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PROWERSOSE (SYENITIC LAMPROPHYRE) FROM TWO BUTTES, COLORADO[1]

WHITMAN CROSS

In 1896 G. K. Gilbert[2] described in this *Journal* the laccoliths occurring at Two Buttes, in the Arkansas valley, near the eastern border of Colorado and about 150 miles from the mountain front at Canyon City. The igneous rocks of this locality, embracing specimens from two laccoliths and many associated dikes, were submitted to me for determination, but no detailed descriptions have as yet been published. The interest attaching to the principal rock type and some of its associates made a renewed examination of their field-relationships desirable, and such a study is contemplated for the field season of the current year.

The rock of the larger laccolith at Two Buttes possesses an unusual mineral composition, and it was subjected to chemical analysis by W. F. Hillebrand. The analysis, which was published, with a brief description by myself, in the well-known compilation of rock analyses made in the U. S. Geological Survey laboratory,[3] has led to the classification of the rock by the quantitative system in a subrang without other known representatives until the one described by Mr. Bastin in the accompanying paper was discovered. The rarity of such rocks, and the fact that the one from Colorado

[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] "Laccolites in Southeastern Colorado," *Journal of Geology*, Vol. IV, pp. 816–25.

[3] "Analyses of Rocks," tabulated by F. W. Clarke, *Bulletin No. 228* (1904), U. S. Geological Survey, p. 186.

has received practically no petrographic discussion, make its description at this time appropriate, although nothing can as yet be added to the general statement of occurrence given by Gilbert, which is summarized below.

Features of occurrence.—The rock forms the lower of two laccoliths, of an extent not clearly determinable, owing to surficial gravels. The horizons of intrusion of the known masses are in Triassic Red Beds, but a few hundred feet below Cretaceous strata. The lower Cretaceous beds are upturned about the laccolith, and Gilbert considers it probable that the intrusions occurred either in "the closing epochs of the Cretaceous or the earlier half of the Eocene." The outcrop of the rock to be described "is nearly continuous for three-fourths of a mile from north to south and more than half a mile from east to west." While it is not desired to present details of occurrence here, it may be noted that Gilbert observed some fifty dikes traversing the sediments of horizons above that of the laccoliths, and that many of these dikes belong to the type under discussion. The upper and probably smaller laccolith, separated from the lower one by a few feet of limestone, is composed of very similar material.

General description.—The rock of Two Buttes submitted to analysis is fine-grained, greenish-gray, with a habit sometimes exhibited by minette. Its most prominent megascopic constituent is biotite, occurring in glistening brown, hexagonal plates 2^{mm} or less in diameter, with a few blades 1^{cm} long. There are a few reddish-brown phenocrysts, 2 or 3^{mm} in length, representing original olivine, now wholly replaced by serpentine and chlorite, and colored by iron oxide.

A hand lens reveals many prisms of pale-green augite, and an abundance of feldspar is evidently present as interstitial material. A few aggregates of feldspar grains are scattered irregularly through the mass, but there are no normal phenocrysts. The lens also shows many minute pores, but the rock is so fresh that these seldom contain secondary minerals. The fractured surface is rough or hackly.

Microscopic characters.—Under the microscope this rock is found to consist essentially of a feldspathic base holding, besides the mega-

scopic phenocrysts, many small biotite leaves, augite grains and prismoids, and a multitude of minute magnetite grains. There is a gradual transition from the minute biotite and augite individuals to those 2 or 3^{mm} in diameter—a feature which causes the porphyritic texture to be subordinate and crude.

Feldspar is the most abundant constituent, and it seems to be wholly orthoclase, occurring in ill-defined scales or tablets which are characteristically arranged, and possibly intergrown, in sheaf-like, imperfectly radial groups. There are no sharply defined crystals, and the maximum dimension of the particles is perhaps $\frac{1}{8}^{mm}$. Because of the great number of other mineral grains which are held by this orthoclase mass, and through the presence of many minute dustlike interpositions, the feldspathic constituent can be satisfactorily studied only in certain small areas scattered through the rock, where the femic minerals are quite subordinate.

All feldspar on the borders of the sections has a lower index of refraction than the Canada balsam, no multiple twinning has been observed, and the analysis of the rock shows that a soda feldspar is not likely to be present. Probably the orthoclase contains a small amount of the albite molecule.

Biotite is quantitatively the next constituent of importance. It occurs in scales which are seldom crystallographically bounded, the large phenocrysts and some of the smallest flakes being the prominent exceptions. The pleochroism ranges from pale yellow to a reddish brown. It is clear that the mineral is poor in iron. It is quite fresh throughout the rock.

The pyroxene occurs in prismoids, colorless or faint green as a rule, but some of the stouter prisms contain a core of bright grass-green color. The clino-pinacoidal extinction in such cases is about 36° for the green core and 45° for the outer zone. The pyroxene, being fresh and very nearly free from inclusions, was isolated and analyzed by Dr. W. F. Hillebrand, with the result given in Column II of the table, p. 168. Its specific gravity is 3.45 at 25° C.

This pyroxene is a strongly diopsidic augite, and by assuming the Fe_2O_3 to be about one-half too high, the mineral may be calculated to have the composition: $6\ Na_2\ Fe_2\ Si_4\ O_{12}$ (aegirite) $+ 34\ (Na_2R)\ (Al\ Fe)_2\ SiO_6 + 403\ Ca\ (Mg\ Fe)\ Si_2O_6$ (diopside). It is

unusually high in alumina for the augite of a rock with potash strongly predominant over soda.

TABLE OF CHEMICAL ANALYSES

	I	II	III	IV	V	VI	VII
SiO_2	50.41	51.27	1.58	52.26	56.39	57.31	51.75
	0.840	0.855					
Al_2O_3	12.27	3.05	1.00	10.63	12.88	14.71	14.52
	0.121	0.020					
Fe_2O_3	5.71	3.08	None	2.47	2.36	1.21	5.08
	0.036	0.019					
FeO	3.06	4.34	0.87	5.45	3.54	4.37	3.58
	0.045	0.061					
MgO	8.69	14.21	1.22	9.32	7.83	7.80	4.55
	0.217	0.355					
CaO	7.08	22.58	0.68	5.62	4.06	6.90	7.04
	0.128	0.403					
Na_2O	0.97	0.67	Undet.	1.60	1.30	1.35	2.93
	0.016	0.011					
K_2O	7.53	0.06	Undet.	5.99	7.84	6.38	7.61
	0.080						
$H_2O-110°$	0.46	None	None	0.98	1.33	0.18	2.25
$H_2O+110°$	1.80	Undet.	Undet.	1.97	....	....	....
TiO_2	1.47	0.70	....	1.92	2.07	0.40	0.25
ZrO_2	0.019	0.009	....	0.08	....	....	....
CO_2	....	....	....	0.75	....	....	....
Cl	....	....	....	....	....	....	0.05
P_2O_5	0.46	....	0.46	0.98	....	....	0.18
	0.003						
V_2O_3	0.03	....	....	....	....	....	....
NiO	0.04	0.03	....	....	....	....	....
MnO	0.15	0.28	Trace	0.12	....	....	Trace
	0.002	0.004					
BaO	0.23	None	None	....	...	....	0.30
	0.002						
SrO	0.06	None	?	....	....	....	0.07
	100.42	100.27	5.81	100.14	99.60	100.61	100.14

I. Prowersose (syenitic lamprophyre), Two Buttes, Colo.; W. F. Hillebrand, analyst.

II. Augite from I; W. F. Hillebrand, analyst.

III. Portion of I soluble in dilute nitric acid (1:40).

IV. Prowersose (syenite porphyry), Knox county, Maine. George Steiger, analyst.

V. Ciminose (selagite); Monte Catini, Tuscany; H. S. Washington, analyst; *American Journal of Science*, Vol. IX (1900), p. 47.

VI. Ciminose (ciminite), La Colonetta, near Viterbo, Italy; H. S. Washington, analyst; *ibid.*, p. 44.

VII. Fergusose (fergusite), Highwood Mountains, Montana; E. B. Hurlburt, analyst; *Bulletin No.* 237, U. S. Geological Survey, p. 86.

The microscope shows the presence of serpentine and chlorite occupying areas which probably represent original crystals of olivine. Some are large, corresponding to those seen in the hand specimen, while others are very small. The alteration is so extreme, however, that neither by outline nor by indications of the course of alteration can one positively determine this matter.

Magnetite occurs in very numerous particles only 0.01^{mm} to 0.02^{mm} in diameter, and apatite is chiefly developed in minute needles, with here and there a large stout phenocryst, comparable to the augite in size.

The obscure character of the salic constituents led to a careful search for leucite and nephelite, without evidence of either being found. The 5.81 per cent. of the rock soluble in dilute nitric acid contains no appreciable soda, and hence nephelite and zeolites derived from it are excluded.

On the basis of the above description, this rock may be called, in the prevailing nomenclature, a syenitic lamprophyre allied to minette.

The rock contains some small angular and sharply defined inclusions of white color and fine granular texture, which are seen in thin section to consist mainly of orthoclase and very obscure microperthite, with possibly a small amount of some highly sodic plagioclase. These minerals are developed in anhedral grains, and resemble the orthoclase of the rock only in their dustlike interpositions. A few flakes of biotite, prisms of augite, and grains of magnetite larger than those of the rock are scattered through this feldspathic mass. It seems to represent material genetically related to the host, but derived from some deep-seated source. There is no suggestion of fusion or assimilation of the included particles.

Classification by the quantitative system.—The norm of the Two Buttes lamprophyre is given in Column I of the accompanying table. For comparison the norms of the other rocks of which analyses have been given are appended. The figures for IV are taken from Bastin's paper; for V and VI, from Washington's tables; and for VII, from Pirsson's bulletin on the Highwood Mountains.

The position of the Two Buttes rock in the quantitative system

TABLE OF NORMS

	I	IV	V	VI	VII
Salic molecules—					
Quartz			1.0		
Orthoclase	44.5	35.6	46.1	37.8	45.0
Albite	3.9	13.6	11.0	11.5	3.7
Anorthite	6.9	3.9	6.0	15.0	3.9
Nephelite	2.4	....	....	....	11.4
Femic molecules—					
Diopside	20.1	13.9	11.1	15.3	23.8
Hypersthene	....	15.0	15.6	16.2	....
Olivine	8.7	4.9	....	1.8	1.5
Magnetite	6.0	3.4	3.5	2.2	7.2
Ilmenite	2.9	3.6	....	....	0.5
Hematite	1.6	....	....	....	....
Apatite	1.0	2.3	....	....	0.3

I. Prowersose, Two Buttes, Colo. V. Ciminose, Monte Catini.
IV. Prowersose, Knox County, Maine. VI. Ciminose, La Colonetta.
VII. Fergusose, Highwood Mountains.

is shown, by the subjoined analysis of its norm, to be in the subrang *prowersose* (III, 5, 2, 2).

$$\frac{\text{Sal}}{\text{Fem}}=\frac{57.8}{40.3}=1.43<\frac{5}{3}>\frac{3}{5}=\text{Class III, } \textit{Salfemane}.$$

$$\frac{\text{L } (ne)}{\text{F } (or+ab+an)}=\frac{2.4}{55.3}<\frac{1}{7}=\text{perfelic order (5), } \textit{gallare}.$$

$$\frac{K_2O'+Na_2O'}{CaO'}=\frac{80+16}{25}=3.8<\frac{7}{1}>\frac{5}{3}=\text{domalkalic rang (2), } \textit{kilauase}.$$

$$\frac{K_2O'}{Na_2O'}=\frac{80}{16}=5<\frac{7}{1}>\frac{5}{3}=\text{dopotassic subrang (2), } \textit{prowersose}.$$

The *prowersose* from Maine, while lower in salic molecules than that from Colorado, is so much richer in normative orthoclase and albite as compared with anorthite $\left(\frac{K_2O'+Na_2O'}{CaO'}=\frac{90}{14}\right)$ that it approaches the peralkalic rang *orendase*. But its ratio of potash to soda is lower than for the Colorado rock; hence it does not come so near to the perpotassic *orendase* as does the latter. There is no known member of the dopotassic subrang of *orendase* with which the *prowersose* may be compared.

By consulting Washington's tables it will be seen that the only other salfemanes possessing high potash greatly in excess of soda

are the peculiar leucite rocks of the Leucite Hills, Wyoming, orendite and wyomingite. These are, however, so extremely rich in potash that they fall within the peralkalic rang of the gallares and in its perpotassic subrang, *orendase*. Hence they are farther removed from *prowersose* than are other rocks of which analyses are given in the table.

The rock of Washington's tables within the rang *kilauase* which comes nearest to *prowersose*, belongs to the sodipotassic subrang *lamarose*. It is a leucite-absarokite of Yellowstone Park, but in the low total of alkalis (K_2O 3.79 per cent. Na_2O 1.88 per cent.) and in the high magnesia contents (15.96 per cent.) this rock differs so markedly from the *prowersose* that further comparison seems unnecessary.

On the whole, the nearest relatives of the *prowersose* described are two rocks of the Italian province, belonging to the corresponding subrang of the Dosalane class—namely, *ciminose* (II, 5, 2, 2). These rocks, while notably richer in the albite molecule, maintain a strong preponderance of orthoclase.

Another rock with which comparison is particularly interesting is the unique *fergusose* (II, 6, 2. 2), described by Pirsson from the Highwood Mountains. This rock is very near the *prowersose* of Two Buttes in normative orthoclase, albite, and anorthite, but it is so rich in normative nephelite as to be brought within the lendofelic order (6) of the Dosalane class. The close chemical relationship evident in the analyses is made plain systematically by observing that, if somewhat less than 4 per cent. of normative nephelite of this *fergusose* were replaced by any femic molecule, it would be changed to *prowersose*. It may be noted that there is as yet no known rock of the Salfemane class corresponding to *fergusose* in its chemical relations.

Modal characteristics of the rocks compared.—The *prowersose* of Two Buttes clearly belongs to one of the rock groups illustrating the fact, not yet sufficiently recognized among petrographers, that there may be important variations in the mode or actual mineral composition of igneous rocks possessing very similar chemical composition. The most notable variation in this particular group is in the development of biotite on the one side, and leucite (or ortho-

clase) and olivine on the other. That this variation is in large degree dependent on geological occurrence as influencing conditions of consolidation has been pointed out, notably by Iddings[1] and Washington,[2] the latter while discussing the rocks of Monte Catini and La Colonetta of which analyses have been given.

The rocks of the above tables are all intrusive, except the ciminite of La Colonetta, which is a surface flow. The latter is the only one in which biotite is not an important constituent. It contains numerous phenocrysts of augite and olivine, with a few of orthoclase and labradorite in a very dense groundmass, which is "a felt of minute orthoclase and some labradorite laths lying in a glassy base" (Washington).

On the other hand, the selagite or mica-trachyte of Monte Catini has very closely the habit of the Colorado *prowersose*, as I am able to state through examination of a type specimen donated by Dr. Washington to the Petrographic Reference Collection of the Geological Survey. The development of biotite and the megascopic appearance of the groundmass is very nearly the same in the two rocks. Microscopically, the difference in texture is more pronounced, as in the selagite augite occurs in small crystals forming a part of the groundmass, and the orthoclase tables are much more sharply defined than in the Two Buttes rock.

In marked contrast with the syenitic lamprophyre of Two Buttes stands the fergusite or pseudoleucite-syenite of the Highwood Mountains. That rock contains numerous pseudoleucite grains 5^{mm} or less in diameter, held in a matrix consisting chiefly of augite, with small amounts of biotite, olivine, and other accessory minerals.

The great textural difference between the two known types of *prowersose* is most striking. The rock of Knox County, Maine, is a most pronounced porphyry, as a reference to the description by Mr. Bastin, and a glance at the photographic illustration, will show. There are many large alkali feldspar phenocrysts lying in a groundmass of biotite and green hornblende.

[1] J. P. Iddings, "The Origin of Igneous Rocks," *Bulletin of the Philosophical Society of Washington*, Vol. XII (1892), pp. 176, 177.

[2] H. S. Washington, "Some Analyses of Italian Volcanic Rocks," *American Journal of Science*, Vol. IX (1900), p. 49.

SOME UNUSUAL ROCKS FROM MAINE[1]

EDSON S. BASTIN

I. PROWERSOSE FROM KNOX COUNTY

This unusual rock was collected by the writer in the summer of 1905 near Burkettville post-office in Knox County, Maine. It outcrops over a nearly circular area about 3½ to 4 miles across, which lies mainly in the town of Appleton, but extends a short distance west into the town of Washington, and north into the town of Liberty (Waldo County). It intrudes pelite schists and gneisses, and is itself cut by numerous dikes of pink aplitic granite. Bowlders of this rock had previously been observed 20 to 25 miles to the southeast, near the villages of Sprucehead and St. George.

In the field the rock was called a syenite-porphyry. The commonest phase is massive and shows numerous purplish-gray phenocrysts of feldspar in a rather fine, dark-green, even-grained matrix made up almost entirely of biotite and green hornblende (Fig. 1). The feldspar phenocrysts vary in length from ¼ to 1½ inches, 1 inch being about the normal length. A series of measurements on three hand-specimens showed that they constituted about 42 per cent. of the rock. Many are twinned according to the Carlsbad law, and some show zonal structure very perfectly brought out through concentric alternation of yellowish-gray with purplish-gray layers.

Microscopic study shows most of the feldspar to be a perthitic intergrowth or a somewhat irregular interpenetration of orthoclase or microcline, and albite. Microcline and orthoclase may or may not be present in the same crystal. In general, the potassic feldspar dominates greatly over the sodic, so that megascopically no albite twinning is visible in any of the phenocrysts. Some of the smaller phenocrysts are pure microcline, and a very few are pure orthoclase. Albite, not intergrown with the potash feldspars,

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occurs in a few places in aggregates of small grains associated with similar grains of orthoclase, and both grading into the perthitic intergrowths. It also occurs occasionally in small subangular grains inclosed in the large feldspar crystals. Most of the feldspar phenocrysts are full of inclusions. Some are dotted with subangular or rounded inclusions of quartz, and sometimes of orthoclase

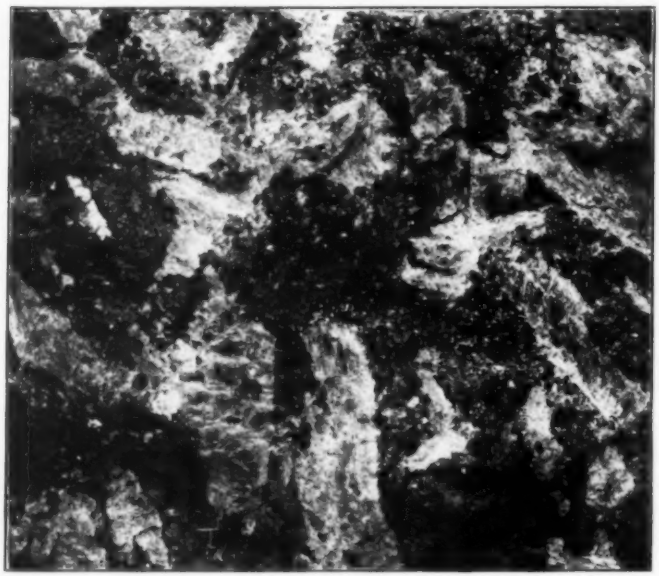

FIG. 1.—Prowersose from Knox County, Maine. Natural size.

and albite, in grains averaging about $\frac{1}{10}$ of a millimeter in diameter; quartz thus included makes up perhaps 2 per cent. of the phenocrysts. Minute prisms of zircon are also of common occurrence. The most abundant inclusions appear hairlike under the low-power, but under the high-power are seen to consist of large numbers of minute, brownish, globular bodies arranged close together in perfectly straight lines. Some of these lines of globules are a millimeter in length. In a few cases the globules are seen to increase in length, so that they form a row of short prisms arranged end to end; these

become more and more elongate until we have a single long, needle-like crystal which resembles the rutile needles common in many quartzes. In certain of the feldspars these inclusions are arranged in two or three intersecting sets which, in some cases at least, parallel the cleavage planes, though in other parts of the feldspar they seem to have every conceivable orientation. Besides those mentioned above, there occur, scattered irregularly through the feldspar, a large number of minute, globular, or prismatic inclusions of indeterminate character.

The zonal structure observed in many of the feldspars is the result of the alternation of bands of only slightly different composition, rather than any considerable and progressive change in composition in passing from the center outward. The index of refraction in this case never rises above that of Canada balsam. Some bands are orthoclase, while others are microcline, and slight variations in composition are also indicated by slight differences in the double refraction and in the extinction angles. Inclusions are very much more abundant in some of the bands than in others, and it is those bands which contain the abundant inclusions that are dark-colored megascopically. This suggests that the peculiar purplish-gray color of certain parts of the feldspar may be due largely, if not wholly, to the inclusions.

The groundmass, when examined microscopically, shows the minerals indicated in the following table:

	Proportions in Groundmass	Proportions in Whole Rock
Biotite	55.5%	29.0%
Hornblende	32.6	19.0
Titanite	6.3	3.5
Apatite	5.0	3.0
Quartz	3.2	3.0
Titaniferous Magnetite	1.6	1.0
Feldspar	0.7	41.5*
Total	99.9	100.0

*An estimated amount of 1 per cent. of quartz occurs as inclusions in the feldspars.

Brown biotite, the most abundant of the ferromagnesian constituents, occurs in plates of various sizes up to 2^{mm} across. All

are perfectly fresh. Within the larger plates inclusions of titanite, often forming a border about ilmenite or titaniferous magnetite, are abundant. Some zircon and numerous apatite prisms are also inclosed.

The hornblende individuals seldom exceed $\frac{1}{2}$ mm in diameter, but are usually grouped in aggregates which may be 2 to 3 mm across. The color is light green, and the pleochroism is not marked. The aggregates inclose some biotite, some titanite, and abundant prisms of apatite.

Titanite occurs abundantly in small grains, but larger aggregates are usually associated with a mineral showing the optical properties of magnetite. This mineral is probably ilmenite or titaniferous magnetite. If forms a core surrounded by rather an even border of titanite, or else occurs in small irregular grains scattered through the central portion of the titanite aggregate. Some of these titanite and titaniferous magnetite masses are over $1\frac{1}{2}$ mm in diameter. This association suggests that the titanite is a decomposition product from the titaniferous magnetite. This decomposition is somewhat remarkable in view of the exceedingly fresh state of the hornblende and the biotite; but it seems improbable that the titanite and titaniferous magnetite are in parallel growth, or that the hornblende and biotite owe their fresh appearance to recrystallization.

Apatite is very abundant in short prisms averaging about $\frac{1}{10}$ mm in diameter. These are inclosed by all the other constituents of the rock, even by the titaniferous magnetite.

Quartz occurs, mainly about the borders of the feldspar phenocrysts, in small grains which are usually aggregated.

Feldspar is present only rarely in the groundmass, and is then usually close to the phenocrysts. It is microcline or orthoclase.

In some of the feldspar phenocrysts we find inclosures which have the same mineral composition as the groundmass. Upon careful examination, these are seen to occur along lines of healed fracture. When several such inclosures occur in the same phenocryst, they seem to be connected by an irregular band of feldspar differing slightly in appearance from the rest of the phenocryst. This difference may consist (1) in a lesser abundance of minute inclusions,

(2) in a slight difference in the proportions of the two feldspars in the microperthite, or (3) in a slight difference in the form of the bands, where the feldspar is microperthite. Along this zone we may also find small, scattered crystals of hornblende or of biotite. This phenomenon indicates a fracturing of the phenocrysts before the groundmass was completely crystallized, the introduction of

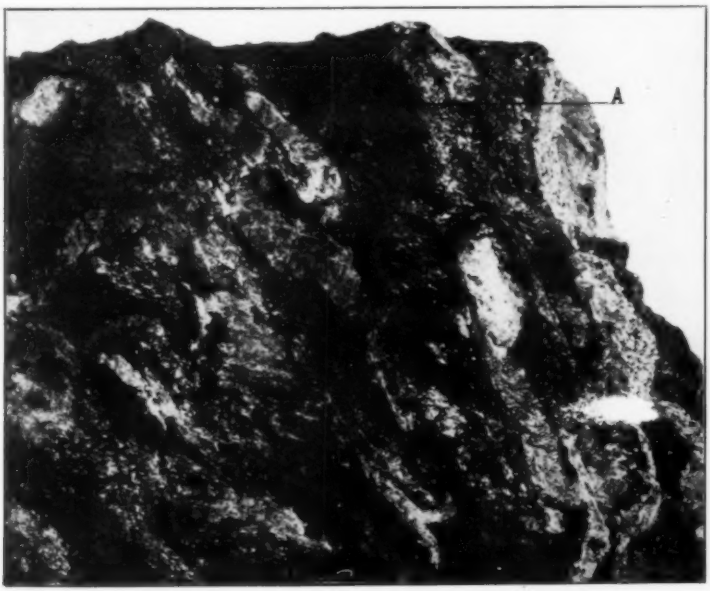

FIG. 2.—Sheared specimens of Prowersose from Knox County, Maine. Nearly natural size. Face slightly inclined to the schistosity. A=one of the mica-coated phenocrysts.

portions of the groundmass into the fracture, and the healing of the fracture, probably by crystallization out of the mother-liquor.

The feldspar phenocrysts seem to have been developed early in the crystallization of the rock, though antedated by the small quartzes and feldspars which they inclose. It is possible that they were fully grown before crystallization of the groundmass commenced. None of the slides show clearly that the feldspars inclosed

portions of the groundmass in any other way than that described above. Of the minerals of the groundmass, apatite seems to have been the first to crystallize, followed by titaniferous magnetite, biotite, quartz, and hornblende. In only a few instances is the hornblende inclosed in biotite, but the reverse relation is very common.

Near the border of the area the porphyry has, in many places, been considerably sheared. The feldspars for the most part remain intact, though showing some fracturing and bending under the microscope. They have become coated, however, with a "skin" of secondary biotite which adheres even after they have weathered out from their matrix (Fig. 2). Except for this development of mica, the sheared rock differs but little in microscopic appearance from the unsheared.

The chemical analysis, and the classification of this rock according to the quantitative system, are given in the tables on the opposite page.

According to Washington's[1] table of rock analyses, the only other known rock falling in this subrang is one collected by G. K. Gilbert from Two Buttes, Prowers County, Colo., and briefly described by Whitman Cross.[2] This is a laccolitic rock, and has as its chief constituents diopside, alkali feldspar, considerable biotite magnetite, and olivine. The ferromagnesian minerals predominate.

These rocks are peculiar in their high alkali content and in the preponderance of potash over soda. The only other highly alkaline rocks (perkalkalic or domalkalic) of this class which show a corresponding preponderance of potash (perpotassic or dopotassic) are wyomingose, madupose, and orendose from the Leucite Hills of Wyoming, chotose from the Bearpaw Mountains of Montana, and albanose from the Alban Hills of Italy. All of these rocks show leucite in the mode, and in all except orendose it is present also in the norm. In orendose the high potash content is indicated by the presence of potassium metasilicate in the norm. In prower-

[1] H. S. Washington, "Chemical Analyses of Igneous Rocks," *Professional Paper No. 14*, U. S. Geological Survey, p. 313.

[2] See *Bulletin No. 228, U. S.* Geological Survey, p. 186.

	Prowersose from* Knox Co., Maine	Prowersose from† Two Buttes, Prowers County, Colo.
SiO_2	52.26 0.871	50.41 0.840
Al_2O_3	10.63 0.104	12.27 0.120
Fe_2O_3	2.47 0.015	5.71 0.035
FeO	5.45 0.076	3.06 0.043
MgO	9.32 0.223	8.69 0.217
CaO	5.62 0.100	7.08 0.127
Na_2O	1.60 0.026	0.97 0.016
K_2O	5.99 0.064	7.53 0.080
H_2O+	1.97	1.80
H_2O-	0.98	0.46
TiO_2	1.92 0.024	1.47 0.018
P_2O_5	0.98 0.007	0.46 0.003
MnO	0.12 0.002	0.15 0.002
ZrO	0.08 0.001	....
CO_2	0.75	....
BaO & SrO	....	0.29
V_2O_3 & NiO	....	0.07
Total	100.14	100.42

* Analysis by George Steiger, Laboratory of U. S. Geological Survey

† Analysis by W. F. Hillebrand, Laboratory of U. S. Geological Survey.

NORM OF PROWERSOSE FROM KNOX COUNTY, MAINE, CALCULATED FROM THE ANALYSIS

Orthoclase	35.58%
Albite	13.62
Anorthite	3.89
Diopside	13.90
Olivine	4.91
Hypersthene	15.04
Magnetite	3.48
Ilmenite	3.65
Apatite	2.35
Zircon	0.18
Water	2.95
Carbon dioxide	0.75
Total	100.27

Class, $\frac{\text{Sal.}}{\text{Fem.}} = \frac{53.09}{43.51} = <\frac{5}{3} > \frac{3}{5} = \text{III}$, Salfemane.

Order, $\frac{Q}{F} = \frac{O}{53.09} = <\frac{1}{7} = 5$, Gallare.

Rang, $\frac{K_2O + Na_2O}{CaO} = \frac{90}{14} < \frac{7}{1} > \frac{5}{3} = 2$, domalkalic, Kilauase.

Subrang, $\frac{K_2O}{Na_2O} = \frac{64}{26} < \frac{7}{1} > \frac{5}{3} = 2$, dopotassic, *Prowersose*.

sose the only potash minerals in the mode are biotite, microcline, and orthoclase, while in the norm only orthoclase is present.

II. ALBITE-PYROXENE-SYENITE

These rocks form part of a series of greenstones which have a more or less scattered distribution over an area of about 250 square miles among the islands of Penobscot Bay. The largest continuous area is on North Haven, where they occupy all but the extreme southern parts of the island. From North Haven they extend northwestward to Islesboro and the islands south of it; eastward they extend to the western part of Deer Isle; to the north they reach the mainland in the vicinity of South Brooksville.

The greenstone series consists of diabases, basic trachytes, and albite-pyroxene-syenites, which in very many places show the characters of surface volcanics in the occurrence of tuffs, breccias, and amygdaloidal phases, and in the development of columnar parting and "bolster" or "pillow" structure. Most of these rocks show considerable alteration, but enough moderately fresh specimens occur to place their original character beyond doubt.

It is difficult to estimate the exact proportion which the albite-pyroxene-syenite bears to the trachytes and diabases, but it probably constitutes nearly, if not quite, one-half of the greenstone series. Its normal phase is massive, and it is usually associated with the other greenstones and with the neighboring acid volcanics in the form of dikes and sills. In a few cases, as will be described later, it shows the characteristics of a surface volcanic. With most of the other rocks of this region, it has been affected by regional metamorphism, and in numerous localities a slight schistosity has been developed.

Intrusive phases.—The commonest type of albite-pyroxene syenite is a massive to feebly schistose rock, usually dark green in color, or showing a mottling of light and dark green, the light-green portions representing somewhat altered feldspar areas, and the dark-green the ferromagnesian constituents; in some of the more feldspathic phases the feldspars are almost pure white.

Upon microscopic examination, the texture is usually found to be poikilitic. In some specimens this texture is rendered irreg-

ular by the great variations in the size of the feldspar individuals, while in others it has been obscured or destroyed in the development of a schistose structure or in the weathering. The feldspars are striated and usually form rather short prisms, most of which range from $\frac{1}{2}$ to $1\frac{1}{2}^{mm}$ in length; in many of the slides they are remarkably fresh. They are shown to be albite by their low extinction angles, and by the index of refraction, which is uniformly equal to, or less than, Canada balsam. The pyroxene, which normally forms a poikilitic matrix for the feldspar laths, is pale pinkish-yellow in color, with a hardly noticeable pleochroism, and shows extinction angles ranging up to 45, but usually under 40°. These angles are found in both augite and diopside, but the fact that the angles never exceeded 45° in the half-dozen or so slides studied, as well as certain considerations as to chemical composition to be brought out later, points to the non-aluminous diopside rather than to an aluminous pyroxene. Magnetite is the only other original constituent which plays an important rôle; it occurs in irregular grains, which sometimes assume skeleton forms, and may then partially inclose feldspar crystals.

Near the head of Southern Harbor, on the island of North Haven, the syenite is peculiar in the possession of scattered feldspar phenocrysts which are occasionally $\frac{1}{2}$ inch in length. Relatively fresh representatives of the common massive type are found on Hardhead Island and at the southern end of Spruce Head Island.

Exrustive phases.—Amygdaloidal phases of the syenite were found on the southern end of Bare Island. A part of Mark Island and the greater portion of Beach Island are occupied by a phase of the greenstones characterized by the development of very ragged surfaces on weathering, and by the possession often of a purplish tint which is not characteristic of the greenstones elsewhere. In certain places the weathering reveals a distinctly tuffaceous character. In the field these were looked upon as flows and tuffs, and this is borne out by the microscopic examination, which shows them to be a very fine-grained phase of the albite-pyroxene-syenite series. The rock shows a diabasic texture with laths of albite, varying considerably in size, but mainly minute; between them is chlorite, epidote in small grains, and somewhat altered magnetite.

Weathering and shearing effects.—Even those occurrences of the syenite which, in the hand-specimen, appear massive and very fresh, show under the microscope traces of dynamic action and of very considerable weathering. Distinctly, though not highly, schistose phases are even commoner than the massive phases, and are usually much more altered mineralogically. In a few of the less schistose phases considerable pyroxene still remains, but even here some of this mineral has decomposed with the development of hornblende. In the more schistose phases the femic constituents are green hornblende, fibrous actinolite, and chlorite; in some only chlorite remains. Albite has resisted decomposition much longer than a calcic feldspar would have done under the same conditions. The laths often show fracturing, a pulling apart of the fragments, and their rotation, partial or complete, so that their longer axes lie in the plane of the schistosity. The rotation of the feldspars contributes to the development of the schistose structure, which, however, is due primarily to the distribution of the chlorite in long irregular bands, to some parallelism among the shreds of fibrous hornblende, and to the distribution of secondary epidote grains in irregular aggregates which are elongate palallel to the bands of chlorite. Occasionally some muscovite is developed and aids in defining the schistosity. Magnetite is usually largely altered to titanite or leucoxene. Zoisite, calcite, apatite, biotite, and chloritoid minerals are minor secondary constituents which are sometimes present. Very rarely serpentine has been abundantly developed, as in the intrusive mass which forms the 80-foot hill just east of the steamboat landing at Eggemoggin on Little Deer Isle.

So far as the writer's knowledge goes, all of the pyroxene-syenites thus far described which have contained albite have also contained nephelite or some calcic feldspar, and in most cases the albite has been a very subordinate constituent. The rock here described is unusual in the abundant association of the non-calcic feldspar, albite, with the calcic mineral, pyroxene. In the absence of sufficient material from localities where the rock was freshest, no chemical analyses could be made, and without such it would be unsafe to attempt an explanation of this association. It may be suggested, however, that the explanation may lie in a deficiency of alumina.

The soda, having a stronger affinity for alumina than the calcium, would appropriate it all in the production of albite, while the calcium would be forced to combine with the iron and magnesia in the formation of diopside.

III. A NEW OCCURRENCE OF CORTLANDITE

In 1886 G. H. Williams[1] described certain peridotites from the Cortland series near Stony Point, N. Y., which were peculiar mainly in the development of large hornblende crystals which served as a poikilitic matrix for olivine grains. It was in the description of these rocks that the term "poikilitic" was first applied. The hornblende crystals occasionally reach a diameter of 4 inches, and frequently show "schillerization." The olivine is usually very fresh. Besides these two constituents, some hypersthene, augite, biotite, and magnetite are usually present; feldspar is sometimes an accessory, but is never important. For this rock Williams[2] proposed the name "Cortlandite."

Professor B. K. Emerson[3] has described a peridotite from Belchertown, Hampshire County, Mass., which exhibits most of the characters of William's rock and to which he has applied the same name, and Williams[1] has published an analysis of a somewhat altered occurrence from Howard County, Md. The analyses of these rocks place them in Class IV Dofemane, Order 1 Perpolic, and Rang 1 Permirlic, of the quantitative system.

The rock to be described below occurs near the village of Penobscot in Hancock County, Maine, in the Bluehill Quadrangle. It forms a single outcrop, hardly 30 feet in length and breadth, located about ½ mile east of Pierce Pond. The ledge rises above its surroundings in such a manner as to resemble a huge half-buried bowlder, but the rock is undoubtedly in place and owes its prominence merely to a superior resistance to glacial erosion. Post-glacial weathering has been very considerable, and a red soil containing scattered

[1] G. H. Williams, "The Peridotites of the 'Cortland Series' on the Hudson River near Peekskill, N. Y.," *American Journal of Science*, Third Series, Vol. XXXI (1886), pp. 26–41.

[2] *Ibid.*, p. 30.

[3] B. K. Emerson, *Monograph XXIX*, U. S. Geological Survey, 1898, pp. 346, 347.

hornblende crystals is the result; on the weathered faces the large hornblendes, some of them 2½ inches across, stand out so as to give a knotty or warty appearance. The rock is exceedingly tough and resistant under the hammer.

The megascopic appearance is very similar to that described by Williams for the type locality. The hand-specimen shows a dark-green to almost black rock, with hornblendes ranging from ½ to 2½ inches in diameter; when held at the proper angle, these reflect the light as units, but show numerous dull, irregular inclusions from $\frac{1}{32}$ to $\frac{1}{8}$ of an inch in diameter, which under the microscope prove to be olivine or its alteration product, serpentine, with an occasional crystal of pyroxene. Light-brown biotite is the only other mineral recognizable megascopically; it occurs between the hornblendes and is quite abundant.

Under the microscope the rock is seen to be only slightly altered. The hornblende is mainly massive, but is occasionally fibrous about the edges of the grains, where some alteration has taken place. The color ranges from light green to light brown; the pleochroism is noticeable, but not very strong, **a** = light yellow, **b** = light green, **c** = light green to light brown. Inclusions of magnetite are abundant in the hornblende and vary greatly in size. The majority are quite irregular in outline, but show a tendency toward elongation in the direction of the hornblende cleavage and toward the possession of straight boundaries in this direction. In some of the hornblende crystals inclusions of magnetite and also of pyrite assume minute needlelike or platelike forms, usually elongate parallel to the cleavage planes, but in some cases occurring in as many as three sets, inclined at widely divergent angles. This latter type of inclusions gives to the mineral, when viewed in reflected light, the peculiar metallic sheen which has been described by Judd and others, and has been termed "schillerization."

Olivine ranks next to hornblende in abundance and occurs in grains of more or less rounded outline, usually inclosed by the hornblende; they vary considerably in size. The characteristic irregular fracturing is present, and a few grains show slight serpentinization along the cracks. The serpentine is usually light-colored and appears gray between crossed nicols; occasionally the yellowish-

green variety is developed. The olivine contains numerous magnetite inclusions, usually very irregular in form, and distributed principally along the cracks; some of the smaller ones show dendritic forms. All are probably of secondary origin.

Hypersthene occurs in irregularly bounded grains. Pleochroism strong, **a**=pale salmon-pink, **b**=pale yellow, **c**=pale green. It occasionally incloses both olivine and biotite. In a few places it shows slight alteration to hornblende.

Biotite is abundant and quite strongly pleochroic, colorless to pale yellow parallel to **a**, yellowish to light brown parallel to **b** or **c**; it seems to be in small part a product of hornblende alteration.

A micaceous mineral showing only feeble pleochroism and interference colors never above yellow of the first order is probably intermediate in character between chlinochlore and pennine. It appears to be uniaxial and optically positive, with the slow direction parallel to the micaceous cleavage (i. e., perpendicular to **c**). The pleochroism is light green for rays vibrating parallel to the base, and colorless for rays at right angles to this.

Magnetite and olivine were the first minerals to crystallize, followed by hornblende, hypersthene, and biotite, the last three being about contemporaneous. The elongation of many of the magnetite inclusions parallel to the cleavage planes of the inclosing hornblende, shows either some secondary magnetite crystallization, or else a partially contemporaneous crystallization of hornblende and magnetite.

Megascopically, the Maine rock differs from the type rock of Stony Point, mainly in showing a much larger amount of biotite. Microscopically, the same difference is apparent, and it is also seen that the colors of the hornblende are much paler in the Maine specimen; in the Stony Point rock this mineral is a dark reddish brown. Some of the Stony Point specimens show feldspar as a subordinate constituent, but here it is wholly absent. The relative proportions between hornblende and olivine seem to be about the same in the two rocks. No chemical analysis was made of the Maine rock, but it is probable that it will fall within the same order as those already analyzed.

The geologic age of the rock here described is uncertain, because

the actual contacts are not exposed. It is associated with a border zone of diorite and gabbro surrounding, and practically contemporaneous with, a large granite mass of probable Devonian age. This association, however, may be accidental, and the Cortlandite may be a considerably later intrusion.

IV. PORPHYRITIC GRANITE FROM SOMERSET COUNTY

The specimen here described was collected by Dr. George Otis Smith in the course of a reconnaissance trip in the summer of 1905, and is worthy of brief notice because of its unusually coarse porphyritic character. Bowlders of this rock are common in Somerset County, and in going up the Carrabassett valley they become more and more plentiful, the rock being found in place in Highland Plantation. Here it forms the divide between Dead River and Carrabassett River, both tributaries of the Kennebec. Where crossed by the county road it shows tabular feldspars 3 to 5 inches in length, and is exposed for several miles. The porphyritic granite does not extend into the adjacent townships to the east and west, and that seen both to the north and south of this locality is more of the normal type. The coarsely porphyritic rock seems to be characteristic of an area a few miles square, which does not, however, represent a peripheral zone, but is more probably a separate intrusive mass in a region quite thoroughly intruded with granite.

The specimen examined by the writer came from well within this area. It shows a number of phenocrysts of feldspar, tabular parallel to the *b* pinnacoid, and lying in approximately parallel positions. The largest of these is 7 inches long, 3 inches wide, and ½ to ¾ of an inch thick. In most of the crystals a very pronounced zonal structure is shown on these side pinnacoid faces, and is seen to be due partly to the greater abundance of muscovite along certain layers, and partly to slight differences in tint which probably correspond to slight variations in composition. A microscopic examination of material from the center and from various points on the periphery of the crystal, using Wright's[1] adaptation of Schroeder's method, showed that there was no considerable or progressive change in composition from the center outward. The

[1] F. E. Wright, *American Journal of Science*, Vol. XVII (1904), pp. 385–87.

feldspar throughout is microcline and orthoclase, occasionally perthitically intergrown with small amounts of albite. The groundmass is a medium-grained association of quartz and potash feldspar, in nearly equal amounts. With these are associated abundant brown biotite and small amounts of muscovite. The texture is granitic.

NOTES ON THE RANGE AND DISTRIBUTION OF *RETICULARIA LAEVIS*[1]

E. M. KINDLE

Progress in stratigraphic paleontology in recent years has been largely along the line of increasing our knowledge of the range and distribution of faunas and of the individual species composing them. The important bearing of this class of knowledge upon questions concerning the evolution and dispersal of faunas is evident. Its interest to the general geologist lies chiefly in the fact that the accuracy with which fossils can be used in correlation is in direct proportion to the completeness of our knowledge of their range.

The rapid growth of stratigraphic paleontology during the last two decades, as compared with preceding decades, is illustrated in the history of the development of our knowledge concerning the distribution and range of *Reticularia laevis*, a well-known Devonian brachiopod. For nearly forty years after it had been described practically nothing was added to the information concerning its distribution and range given by Hall at the time of its description. In 1881 Williams wrote: "Only a few localities are known in which this large fossil is found, and, so far as I can learn, none outside of the state" (New York).[2] Its vertical range was then supposed to be limited to about 3 feet[3] of strata. During the twenty years which have elapsed since this was written the distribution of the species has been extended from a small area in central New York across two other states, and the known vertical range has grown from 3 feet to more than a thousand.

Reticularia laevis first appears in the New York section in the lower part of the Nunda or Portage formation. It belongs normally to the brachiopod fauna of the Ithaca facies of the Nunda or Portage. It has never been found associated with the Naples facies which

[1] Published by permission of the director of the U. S. Geological Survey.

[2] *Annals of the New York Academy of Science*, Vol. II (1881), p. 140.

[3] *Ibid.*, p. 141.

flourished alongside and to the westward of the Ithaca fauna. At the best-known locality of its occurrence *R. laevis* is found abundantly through 3 feet of strata, above and below which it is unknown for a considerable interval. At this locality, which is at the foot of Ithaca Falls, at Ithaca, N. Y., the associated fauna, as determined by the writer,[1] is as follows:

Lingula ligea? r.
Crania sp. r.
Chonetes lepida a.
Chonetes scitula r.
Leiorhynchus mesacostalis
Cyrtina hamiltonensis r.
Spirifer laevis a.
Lunulicardium fragile a.
Paleoneilo filosa a.
Ariculopecten rugaestriatus?
Aviculopecten lautus var. ithacensis r.
Modiomorpha subalata
Grammysia subarcuata r.
Glyptocardia speciosa r.
Nucula diffidens r.
Mytilarca chemungensis? r.
Leda diversa
Pleurotomaria capillaria r.
Orthoceras pecator r.
Tornoceras discoideum c.
Taxacrinus ithacensis

This zone of *Sp. laevis* is about 250 feet above the Genesee shale and near the top of the Sherburne sandstone. It lies below the typical Ithaca fauna at a horizon where more or less intermingling of the Naples and Ithaca faunas occurred. The Ithaca element of the fauna is seen in the brachiopod species, while the western fauna is represented by such forms as *Lunulicardium fragile* and *Glyptocardia speciosa*.

This horizon, from which the species was described by James Hall in 1843,[2] remained the only one known for it till forty years later, when Williams found it near the top of the Ithaca fauna,[3] at a single locality in the Fall Creek section about 400 feet higher.

While studying the Ithaca fauna in 1896 the writer found a third zone of *Reticularia laevis* at Ithaca in the McKinneys Station section, which is 120 feet below the zone at the foot of Ithaca Falls.[4]

The discovery of this third zone extended the known vertical range to about 520 feet. The upper zone of the species at or near the top of the Ithaca group had not been relocated since its discovery

[1] *Bulletins of American Paleontology*, No. 6 (1896), p. 17.

[2] Geology of New York, *Report of Fourth District* (1843), p. 245, fig.

[3] *Bulletin No. 3*, U. S. Geological Survey, 1884, p. 20.

[4] *Bulletins of American Paleontology*, No. 6 (1896), p. 28.

by Williams in the early eighties, until the areal survey of the Watkin's Glen quadrangle was undertaken. During this survey the writer found it at several localities near the top of the Ithaca group. In this zone *Reticularia laevis* is associated with typical Ithaca species, such as *Leptostrophia mucronatus*, *Spirifer mucronatus* var. *posterus*, and *Pugnax pugnus*. This zone near the top of the Ithaca member lies about 650 feet above the Genesee shale. No higher occurrence of the species within the Nunda formation is known. The few fossils which occur in the upper half of the Nunda sections near Ithaca belong to the Naples or western facies, a facies with which *Reticularia laevis* has nowhere been found associated. In the Brookton section, near Ithaca, the writer found a fourth zone of this species entirely above the Nunda, and very near the base of the Chemung formation. Here *R. laevis* occurs in abundance in the same bed with *Spirifer disjunctus*, which is also abundant. This, the highest known horizon of *R. laevis*, is not more than 50 feet above the base of the Chemung, and lies about 1,300 feet above the Genesee shale.

We are indebted to J. M. Clarke and D. D. Luther for the recorded observations on the range of the species to the east and west of Ithaca. Hall, in his orignal descriptions, reported the species to occur[1] on the "shore of Seneca Lake," but gave no definite locality, and the species was not found by subsequent workers in the Seneca basin until a comparatively recent date. In 1885 Clarke wrote: "I do not know of its occurrence[2] west of Tompkins County." In Clarke's first report on the Portage faunas of the Seneca basin *R. laevis* does not appear. In the recent paper by Clarke and Luther it is recorded from a single locality near Montour Falls. In this region Mr. V. H. Barnett and the writer found this species at the locality cited by Clarke and Luther, and also in the Watkins and Havana Glen sections. It occurs in the Watkins Glen section about 185 feet above the level of Seneca Lake. These occurrences in the Seneca basin are within the horizon occupied by the Ithaca fauna in the section. The Naples facies has largely supplanted the Ithaca facies in the Seneca section, greatly reducing the thickness of the portion of the column occupied by it.

[1] Geology of New York, *Report of Fourth District* (1843), p. 245.

[2] *Bulletin No. 16*, U. S. Geological Survey, 1885, p. 66.

Eastward of Ithaca, *R. laevis* has not been found beyond the valley of the Chenango River. The easternmost localities known in the New York area are the McGrawville section 4 miles east of Courtland, East Homer,[1] and the Cowles Hill section at Greene.[2] In the region intervening between the Cayuga section and the Chenango valley, *R. laevis* has been found at a number of localities during the survey of the quadrangles in this district. Its occurrence in this area has also been recorded by Clarke and Luther.[3] East of Ithaca the Ithaca brachiopod fauna extends upwards, filling the upper part of the Nunda column, which was occupied by the Naples facies to the westward before the Tiognioga River is reached. All of the occurrences of *R. laevis* in this region are associated with the Ithaca fauna.

The occurrence at Greene represents the highest horizon attained by the species in this eastern region. It occurs here above the Oneonta sandstone in what Clarke calls a "proemial Chemung fauna,"[4] and "not less than 1,200 feet above its first appearance"[5] at Ithaca, according to this author. In this section *R. laevis* occurs with *Leptostrophia mucronata*, an Ithaca species, and no Chemung fossils are reported as occurring with it, so that Clarke's conclusion as to its post-Nunda age is based presumably upon stratigraphic grounds. The discovery of *R. laevis* and *Sp. disjunctus* in association, by the writer, as already noted, however, leaves no question as to the fact that *R. laevis* appears in the New York section as late as the lower part of the Chemung.

In Pennsylvania *R. laevis* has been found at only two localities. These are on the Susquehanna River, in sections studied by the writer at Hollowing Run and Catawissa. In both of these sections the species is found associated with the fauna of the Ithaca facies. In the Catawissa section *R. laevis* occurs at two horizons. The lower faunule in which it occurs contains:

Cystodictya meeki (a)	Nucula sp. (r)
Cyrtina hamiltonensis (r)	Palaeoneilo plana (c)
Spirifer mucronatus var. posterus (r)	Leda diversa (r)
Sanguinolites (?) sp. (r)	Actinopteria perstrialis (a)

[1] *Fifteenth Annual Report*, New York State Geologist, 1895, p. 72.
[2] *Ibid.*, pp. 37–39. [3] *Bulletin No. 82*, New York State Museum, p. 64.
[4] *Sixteenth Annual Report*, New York State Geologist, 1896, p. 36.
[5] *Fifteenth Annual Report*, New York State Geologist, 1895, p. 39.

This lower zone lies 480 feet, and the second zone 1,380 feet, above the Genesee shale, so that the species in this section has a known range of 900 feet.

In the Hollowing Run section, which lies about 25 miles southwest of the Catawissa section, *R. laevis* was found at only one horizon. Its occurrence in this section is not far from the horizon of the lower *R. laevis* zone in the Catawissa section.

In Pennsylvania the Naples and Ithaca facies of the Nunda hold the same geographic relation to each other that they do in New York, the first occupying the westerly, and the second the easterly, sections of the Nunda. The Altoona section, which has been studied by Mr. Charles Butts and the writer, lies well to the west of the Susquehanna sections, and within the area of the dominance of the Naples facies. Neither *R. laevis* nor any other faunal element of the Ithaca facies was found in it. The limitation of the known occurrence of *R. laevis* to two sections is doubtless due to the fact that these are the only sections which have been carefully studied within the area where this species may be expected to occur. It is safe to predict that *R. laevis* will be found in many of the more easterly sections of the Nunda from the New York to the Maryland line, and that it will not generally be found in the westerly sections.

A collection of fossils from West Virginia recently submitted to the writer by Mr. George Stose for determination contains two specimens of *R. laevis*.[1] They occur in association with a brachiopod fauna representing the Ithaca facies of the Nunda. They were collected on Yellow Spring Run, 3 miles southeast of Berkley Springs, W. Va. Mr. Stose's collection represents the most southerly occurrence of the species which has been discovered. The determination of these West Virginia specimens gives the species a known distribution in a northerly and southerly direction of about 225 miles. In New York its distribution in an easterly and westerly direction appears to be limited to about 60 miles. In the southern part of its range we have as yet no data for determining its distribution in this

[1] The Hancock quadrangle in which this species was found is being surveyed co-operatively by the Maryland and United States Geological Surveys, and the writer is able to publish these data through the courtesy of Professor W. B. Clarke, director of the Maryland Geological Survey.

direction, but it may be stated that it will probably be found to coincide with the distribution of the Ithaca facies of the Nunda.

The maximum range of the species, as shown by the New York sections, extends from near the base of the Nunda into the lower Chemung. It has, however, been found at a post-Nunda horizon in only two of the many sections in which it is known.

THE HOT SPRINGS AT THERMOPOLIS, WYOMING[1]

N. H. DARTON

At the southern end of the Bighorn Basin there is a great hot spring which presents some notable geologic features and an interesting question as to the source of the hot water. The spring is at the town of Thermopolis, a village and health resort which owes its existence largely to the reputed therapeutic value of the water. The locality is on the bank of Bighorn River, a few miles north of a high range which may be regarded as the southwestern continuation of the Bighorn Mountains. There are several springs, but one of them has by far the greatest volume. They issue from the red beds, here brought to the surface by a prominent local anticline. The present springs and their predecessors—for the region has been one of thermal activity for many centuries—have built extensive terraces of travertine or hot spring deposits similar to some of those in the Yellowstone National Park.

The geologic structure at Thermopolis is relatively simple and, owing to the extensive exposures of the formations, it is perfectly plain. The cross-section (Fig. 1) shows the relations from the crest of the Bighorn uplift in the mountain summit 10 miles south to a point a few miles north of the springs.

South of the springs there is the long monocline constituting the north slope of the anticline of Bighorn Mountains, and in the vicinity of Thermopolis this monocline is crenulated by a sharp anticline. The axis of this flexure crosses Bighorn River a short distance north of Thermopolis, and along it there are exposed the Chugwater red beds, while on either side is a succession consisting of Sundance (Jurassic), Morrison, Cloverly ("Dakota"), and Benton formations. The dips on the south limb of the anticline are steep, 50° to 65°, while those on the north side are gentle. The Cloverly sandstone on either side gives rise to a prominent "hogback ridge,"

[1] Published with permission of the Director of the U. S. Geological Survey.

as shown in the distance in the upper view in Fig. 2, facing a region of red bed hills about a mile wide and with outer slopes descending into valleys of Benton basal shales. Thermopolis is on the eastern limb of the anticline, the village extending across the outcrop zones of the Sundance, Morrison, and Cloverly formations, locally covered by an alluvial plain which extends back a few hundred rods from the river. There is no evidence of igneous rocks in the region.

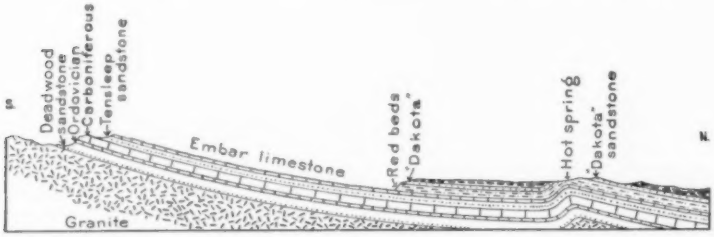

FIG. 1.—Section through the hot springs at Thermopolis, Wyo. Looking west. Length of section about fourteen miles.

The springs rise from the middle beds of the Chugwater formation, apparently through a number of deep cracks. The largest one issues from the foot of a high bank of 80 feet of red sandstones, as shown in Figs. 2 and 2*a*, with a volume stated to be over a thousand gallons a second. The water is clear and hot, having a temperature of 135°. It flows over a wide terrace built of hot-spring deposits, over the edge of which it falls into the river. A part, however, is diverted into conduits of various kinds which lead to the various bathhouses, and to the reservoirs in which a portion of the water is cooled so that it may be used for diluting the hot water to the required temperature for bathing. The spring flows with great force, and evidently comes from considerable depth under high pressure. Numerous algæ of various colors grow in the hot and cooling water, as in the Yellowstone Park and other places. Besides the main spring, there are on the east side of the river a deep, hot pool which does not overflow and, some distance farther north, a hot sulphur spring which gushes out of the travertine bank a few feet above the river. On the west side are several small springs, one of which is utilized for a bathhouse and swimming-

pool. An analysis of the water from the great spring, by Professor E. E. Slosson is as follows:

ANALYSIS OF WATER FROM HOT SPRINGS AT THERMOPOLIS, WYO.

	Grains per Gallon
SiO_2	4.986
Fe_2O_3 and Al_2O_3	0.227
K Cl	10.249
Na_2SO_4	15.110
Mg_2SO_4	19.443
Ca SO_4	13.156
Ca CO_3	40.454
Na Cl	26.195
Total	129.820

Hot Spring deposits.—The hot-spring deposits in the vicinity of Thermopolis indicate a long period of accumulation, for they occur on several distinct terraces, some of which date back probably to Tertiary time. The most recent deposits are being laid down on a broad terrace about 30 feet above the river, which is being built up very gradually. No precise estimate has been made of the rate of increase, but objects placed in the water are rapidly coated with the deposit, and a thickness of an eighth of an inch is accumulated in a short time. There are wide areas of the deposit on both sides of the river below the present springs, which were formed at no distant date, while, on the buttes which rise above this terrace level, there are caps of hot-spring deposits at various elevations. Some of the relations of these are shown in Figs. 3 and 4. The highest deposit caps a prominent butte near the cemetery, at an altitude of about 700 feet above the river. A larger terrace remnant remains on a butte which rises immediately west of the river to a height of about 350 feet above the water. It is probable that these terraces represent three distinct stages of deposition, and, although possibly hot-spring action has been continuous since the formation of the first or highest terrace, most of the deposits at intermediate levels have been removed. As travertine is often deposited on slopes, it is possible that the hot-spring waters issuing at the level of the higher buttes flowed to somewhat lower levels, with a continuous

deposit from one to the other. It is evident, however, from the relations that there has been extensive erosion since the earliest period marked by the higher terraces on which the travertine caps are now found. The high butte near the cemetery—the one shown to the left in Figs. 3 and 4—is probably the remnant of a much

FIG. 2.—Travertine terrace of the Great Hot Spring on the east bank of Bighorn River near Thermopolis, Wyo. The spring is under the *S*. In the foreground are extinct hot-spring craters and a low ridge with long fissure in its summit. Shows upturned red beds and overlying formations.

more extended sheet of the travertine which was largely removed prior to or during the development of the lower terraces.

It is evident, from the disposition of the material, that the springs have shifted their position, but in general the outflow has been in the immediate vicinity of the crest of the anticline. The hot-spring deposits show remnants of numerous hot-spring craters and cracks, some of the most marked of which are on the terraces near the river. On the west bank, a short distance north of the bathhouse, there is an empty crater 30 feet in diameter, shown in Fig. 2, indicating the former existence of a large hot pool, and there is another similar

crater of still larger size, a short distance northeast of the sulphur spring on the east bank. One of the same character, but much less distinct, is found on the high terrace west of the cemetery 500 feet above the river. It is probable, from the present appearances

FIG. 2a.—Terrace of hot-spring deposit on the bank of Bighorn River. Looking south to Thermopolis, with Owl Creek Mountains in the distance. Shows overflow of hot spring.

of the deposits, that formerly the hot-spring activity was much greater than at present. Whether or not there were geysers is difficult to state, but some of the features of the deposits strongly suggest

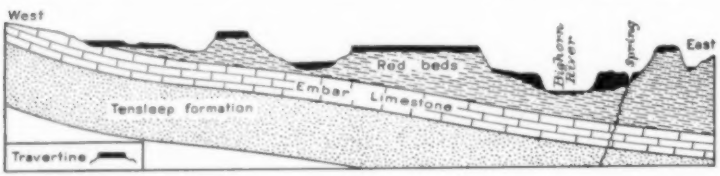

FIG. 3.—Cross-section of travertine terraces a short distance north of Thermopolis, Wyo. Looking north. Length of section about one mile.

that if the water was not thrown out by geyser action, it at least flowed in large volume.

Source of the water.—The source of the water in the Thermopolis springs is difficult to ascertain, but undoubtedly the flow is not derived from the adjacent Red beds, nor from the underlying Embar limestone. Probably the strata are somewhat fractured in the

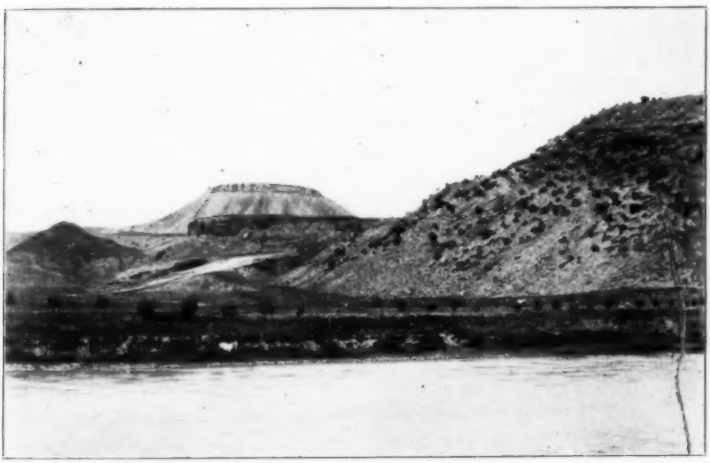

FIG. 4.—Hot Spring deposits on old terraces at various heights in western part of Thermopolis, Wyoming. Looking south across Bighorn River.

crest of the arch and permit the escape of the water from deep-seated sources. One of the most likely of these might be thought to be the porous Tensleep sandstone which outcrops high on the mountain slopes southward. It undoubtedly carries a water supply which passes beneath the syncline south of Thermopolis, and retains sufficient head to rise to and above the surface in any vent to the northward. If the water is from no greater depth than this horizon, there is difficulty in accounting for the high temperature, for the top of the sandstone does not lie at a greater depth than 500 feet at the spring and 2,000 feet in the bottom of the syncline a short distance south. Assuming that the mean annual temperature at Thermopolis is 50°, and that the temperature of water increases one degree for every 50 feet underground below

the first 50 feet—where the mean annual temperature is the underground temperature—a depth of 4,300 feet would be required for the spring water to become heated to 135° under ordinary conditions. As the granite probably lies only 2,500 feet below the spring, or 4,000 feet below the surface in the syncline south, this rate of increase would indicate a source at least as low as the base of the Deadwood formation. If the water is derived from the basal sandstone of that formation, it passes underground in the outcrop area in the high mountain slopes to the southeast, and becomes heated in the bottom of the syncline a short distance south of Thermopolis. In order to preserve this heat in its course to the outlets, there must exist cavernous channels affording rapid flow, as heat would be lost in slow percolation through the interstices of the rock. It is possible also that the source of the water is much less deep, and the heat may be due to deep-seated igneous rocks in this vicinity, which have not yet cooled. As the nearest outcrops of igneous rocks are in the Shoshone Mountains 40 miles west, it appears improbable that there are any intrusions under the Thermopolis region.

THE SEDIMENTARY ROCKS OF SOUTH MOUNTAIN, PENNSYLVANIA[1]

GEORGE W. STOSE

The area described in this paper is the western portion of South Mountain, Pa., and the adjacent part of the Cumberland Valley from near the Maryland state line to the vicinty of Shippensburg, Pa. It is about 15 miles in length. The accompanying topographic map of this area (Fig. 1) is taken from the Chambersburg sheet of the United States Geological Survey and the South Mountain atlas of the Pennsylvania Geological Survey. South Mountain is the local name for the Blue Ridge which parallels the Great Valley of the Appalachian Province on the east, and Cumberland Valley, a section of the Great Valley.

TOPOGRAPHY

The Cumberland Valley is a broad, rolling lowland extending from the Potomac River to the Susquehanna River. Its general elevation is from 400 to 800 feet, and scattered, low eminences rise to 1,100 feet. These hills are usually of the rounded form characteristic of limestone country, but in part they are shale tablelands with steep escarpments. The valley has a width of approximately 13 miles in the vicinity of Harrisburg, but expands to 20 miles in the area under discussion. The southern half of the valley is drained by Conococheague Creek and its tributaries into the Potomac, the northern half by Yellow Breeches Creek into the Susquehanna.

South Mountain is a more or less irregular aggregate of ridges with a general northeast-southwest trend. Although cut across by numerous gaps, and deflected in places by sharp bends, the ridges maintain a marked continuity. The mountain front rises abruptly from the plain to elevations of 1,700 or 1,900 feet. The interior ridges are generally higher, reaching 2,100 feet in places, whence they decline again eastward into lower hills.

[1] Published by permission of the Director of the U. S. Geological Survey.

FIG. 1.—Topographic map of South Mountain in southern Pennsylvania, and adjacent portion of Cumberland Valley.

From the Potomac to the Maryland-Pennsylvania state line the mountain has approximately a straight, unbroken course nearly due north. At the East Branch of Little Antietam Creek, in the southeast corner of the area shown on the accompanying map, there is an offset of the mountain front of about one mile westward, the ridges on the north side lying farther into the valley. A short distance to the north another offset into the valley, of about 2½ miles, is produced by the sharp bend of the ridges to the westward, beyond which they again assume their northeasterly course, as may be seen on the map. North of Conococheague Creek another offset of 3½ miles is produced by the development to the westward of another ridge, broad and flat-topped, and dissected by numerous deep lateral valleys. This Big Flat Ridge has an altitude of over 2,100 feet, the highest point of South Mountain in Pennsylvania.

The drainage of the mountain area is accomplished by the East Branch of Little Antietam Creek and Conococheague Creek and their tributaries. The former rises some distance east of the area represented on the map, and flows southwestward directly across the ends of the ridges on the north side of its valley, but nearly parallel to the ridges on the south side. Its tributaries are all short, and form longitudinal valleys between the ridges on the north. The West Branch of Little Antietam Creek drains a portion of the Cumberland Valley adjacent to the mountains, and has its headwaters in the short longitudinal valley which outlets at the gap east of Montalto.

Conococheague Creek heads far beyond the border of the mapped area, and, after flowing southwestward in a longitudinal valley, turns abruptly westward through a gap in the ridges. It has several large tributaries which drain the interior of the mountain area in this vicinity, chief of which are Newmans Branch, a transverse stream from the east, and Rocky Mountain Creek, a longitudinal stream from the south. Numerous short tributaries head in the deep ravines on the east flank of Big Flat Ridge. Others on the west side of the ridge find underground courses beneath the covering of wash on the surface, or sink into limestone caverns before they reach the main stream. The waters of both Conococheague and Little Antietam creeks ultimately reach the Potomac River to the south.

GEOLOGY

The rocks in this area are largely concealed by the sandstone débris which covers the mountain tops as well as the valleys and slopes. Their character, thickness, and relation are therefore not readily determined. The structure is also complicated by schistosity and jointing which exist in all these rocks. The mountains are composed of Georgian (Lower Cambrian) quartzites, sandstones, and shales, and older igneous rocks; the adjacent portions of the Valley of Cambrian and Ordovician limestones and shales.

STRATIGRAPHY

Old volcanics.—The basement rocks exposed in the area are ancient volcanic rocks, greenstone and altered rhyolite, which underlie the basal Cambrian uncomformably. They occupy the plateau-like tract overlooked by higher peaks in the center of the mountain area shown on the map and in the extreme southeast corner, and are extensively developed to the eastward. The volcanic origin of these ancient rocks is clearly shown by flow banding, amygdaloidal structure, and spherulites, as described by Williams[1] and Bascom.[2] The greenstones are sheared dense rock, veined with asbestos and chlorite. The original structure is seldom preserved, but the rock is apparently an altered basalt. The rhyolitic rocks are of purple and red tints, often porphyritic and frequently banded by flow structure or spherulitic streaks. The rhyolitic rocks predominate in this area, and apparently overlie the greenstone, for the basal Cambrian sediments are composed largely of rhyolitic fragments and not of basaltic detritus, as would be the case if the greenstone were younger and had been eroded from most of the area.

Basal sandstones.—Overlying these softer rocks are about 4,500 feet of sandstone, quartzite, and shale of Georgian (Lower Cambrian) age. The basal beds, forming the higher and more rugged portions of the mountains, are composed of coarse, purple and yellowish banded sandstones, fine conglomerate, and arkose, with white

[1] *American Journal of Science*, Third Series, Vol. XLIV, pp. 482–96.

[2] *Journal of Geology*, Vol. I, pp. 813–32, and *Bulletin of the U. S. Geological Survey*, No. 136.

feldspathic and vitreous sandstones above. The purplish conglomerate bed is composed of small pebbles and grains of quartz, feldspar, and purplish slate or tuff, the flat slaty fragments often having a diameter of 2 inches. This grades almost imperceptibly through soft purplish arkose into the reddish rhyolitic eruptives below, demonstrating their derivation largely from similar volcanic rocks exposed along the nearby shore of the Georgian sea. In Maryland, and also at Mount Holly at the north end of South Mountain, basal conglomerates contain numerous large quartz pebbles, probably in part derived from the granitic basement complex of the Piedmont.

This basal sandstone, on account of its hardness, forms high, rugged ridges in the heart of the range, such as Rocky Mountain and Snowy Mountain. It is continuous with the Weverton sandstone of the Catoctin and South mountains, Maryland, as mapped by Keith[1] and the name is therefore used here. The underlying Loudoun formation, which is described by Keith as variable in composition and thickness in Maryland, was not recognized as a distinct formation in this area, but may be represented in the soft arkose at the very base of the sedimentary series.

Upper shales and sandstones.—Above the Weverton sandstone there are about 3,200 feet of shale and soft sandstone in which are two horizons of hard, ridge-making sandstone. The softer beds are poorly exposed, being everywhere covered by the débris from the adjacent sandstones. Their presence is inferred from the fact that their outcrop is always occupied by valleys and depressions. Their character is indicated in part by occasional fragments of thin shaly sandstone and black banded slate or red ferruginous shale. The hard sandstone beds form the ridges along the mountain front and cap the high, flat-topped Sandy Ridge, as well as Big Flat Ridge north of Fayetteville. The lower of the two sandstones is the more massive, and is composed of a hard quartzitic stratum, usually of dark-gray color and veined with quartz, and a softer, granular, white layer containing long, slender *Scolithus* tubes. The upper hard bed at the top of the shale, is a milk-white or slightly pinkish, granular, calcareous sandstone, frequently disintegrating by the removal

[1] "Geology of the Catoctin Belt," *Fourteenth Annual Report of the U. S. Geological Survey*, pp. 285–305.

of the soluble cement to yellowish quartz sand, which is quarried for building purposes. This bed also contains numerous *Scolithus linearis* borings, and in places *Camarella minor* and fragments of *Olenellus*[1] have been found, by which its age has been determined to be Georgian (Lower Cambrian).

In the Catoctin and South Mountains of Maryland Keith has mapped above the Weverton sandstone 800 to 1,200 feet of shale (Harpers), and 500 to 700 feet of sandstone (Antietam). The Harpers shale is typically exposed at Harpers Ferry, on the Potomac River, and, as described by Keith,[2] consists of a bluish-gray shale with a few thin sandstone beds. Northward these sandstones beds are said to thicken, some attaining 50 feet, but do not have an appreciable effect on the topography. On the road from Monterey to Waynesboro, in the southeast corner of the area shown on the map, this series is fairly well exposed, but, according to Keith, the structure is complicated by folding and faulting. Above the Weverton sandstone in this section, as seen by the writer, are shales or slates, in part dark-banded, containing a conspicuous white, *Scolithus*-bearing sandstone 20 to 30 feet thick, all of which is mapped by Keith as Harpers shale. Above the shale is the *Scolithus* sandstone in which Walcott found *Olenellus* and *Camarella minor*, as noted above, and which is mapped by Keith as Antietam sandstone.

North of Little Antietam Creek there are two ridge-making sandstones above the Weverton sandstone, one composing Sandy Ridge and the other Curve Mountain, and between them is black-banded slate with thin ferruginous sandstones. The upper bed forming Curve Mountain is undoubtedly the Antietam sandstone, and it is apparent that one of the sandstone beds in the Harpers shale of Maryland increases in prominence northward, so that in Pennsylvania it reaches such dimensions that it forms a distinct ridge. The Harpers formation in this area therefore consists of shales and soft sandstones, with a quartzitic member near the middle which is here named the Montalto quartzite, from Montalto Mountain. Northward the shale gradually thins, and the sandstone continues to expand until at the northern border of the area it occupies

[1] Walcott, *Bulletin of the U. S. Geological Survey*, No. 134, p. 25.

[2] *Loc. cit.*, p. 308.

TABLE OF GEOLOGIC FORMATIONS FOR SOUTH MOUNTAIN, PA., AND ADJOINING PORTIONS OF THE CUMBERLAND VALLEY

Age	Name		Thickness (feet)	Character
Ordovician	Martinsburg group	Eden sandstone	500	Soft, buff to green sandstone
		Utica shale	1,000	Gray fissile shale, with black, carbonaceous and calcareous shale, probably of Trenton age, at the base
	Shenandoah group	Chambersburg limestone	1,000+	Fossiliferous, crystalline and thin shaly limestones of Chazy-Black River age
		Stones River limestone	400+	Homogeneous, dove-colored, pure limestones of Stones River age
Saratogan (Upper Cambrian)		Knox limestone	2,000±	Drab magnesian and siliceous limestones, in part cherty, with limestone conglomerate at the base
Acadian (Middle Cambrian)?		Elbrook limestone	2,000±	Massive, bluish-gray, magnesian and cherty limestone with some red and green shales
		Waynesboro formation	600±	Purple shale and flaggy sandstones
		Tomstown limestone	800±	Drab to white magnesian and pure limestones
Georgian (Lower Cambrian)		Antietam sandstone	500±	White, calcareous, *Scolithus* sandstone, containing Georgian fossils
		Harpers formation and Montalto quartzite member	2,750±	Dark-banded shale or slate and ferruginous sandstone, with gray to white quartzitic sandstone, containing *Scolithus* tubes in the softer layers
		Weverton sandstone	1,250±	Purple to white feldspathic sandstone, conglomerate, and arkose
Algonkian?		Old volcanics		Altered rhyolite and greenstone

almost the whole interval of the formation, indicating a gradual change from a fine mud deposit in the south to coarser siliceous sediments in the north. Similar conditions may have continued into Antietam time, and have affected the deposition of the Antietam sandstone. The patchy occurrence of the Antietam in the Maryland area, as mapped and described by Keith, may be due to its irregular

deposition in that area, instead of to infolding in the Harpers shale and to faulting, as previously supposed. Irregularity of Antietam sedimentation in the Pennsylvania area also is indicated by the absence of ridge-making character east and southeast of Montalto, where the bed is thin, disintegrated, and inconspicuous.

Shenandoah limestone.—The rocks of the Valley are chiefly light- and dark-gray, massively bedded, magnesian limestones, described and mapped in the northern Appalachian folios of the United States Geological Survey atlas as the Shenandoah limestone. They are so intricately folded, and have so few easily recognized horizons, that the details of the stratigraphy cannot be determined nor the thicknesses accurately measured. The series is estimated to be about 6,800 feet thick, and is here divided into six formations. The lowest, composed largely of drab to white, impure limestones, has near its base beds of purer, mottled, dark- and light-gray limestone, which is frequently quarried and burned for lime, and near its top a massive bed of cherty limestone. The formation is limited above by ferruginous sandstone and purple shale. It is approximately 800 feet thick. The name "Tomstown limestone," here applied to it, is from a village at the foot of South Mountain, where the formation outcrops.

The next succeeding formation is composed largely of hard, siliceous, ripple-marked, purple shale and flaggy, calcareous sandstones, about 600 feet thick. At the base is a siliceous rock weathering into large slabs and masses, stained yellow by iron, and usually banded and contorted. These masses, together with fragments of vein quartz and white porous chert, strew the surface and in places produce a low ridge. Scattered deposits of limonite occur on the slopes of these ridges, produced by the leaching of iron from the ferruginous shale and its precipitation in the soil and wash at the surface. Flaggy sandstone and sandy shale, forming the top of the formation, make a rather continuous low ridge in the limestone lowland, thus affording a marker in the otherwise monotonous series of beds. Shattered portions of this sandstone are veined with barite, and in the soils at the base of the hillslopes the weathered product has in places been concentrated and mined on a small scale. At Waynesboro, in the upper sandy shales and in the immediately overlying lime-

stones, fragments of trilobites and other fossils suggesting Acadian (Middle Cambrian) age, were found by the writer. The sandstone and the purple shale also outcrop conspicuously in the ridge just north of Waynesboro, so the name "Waynesboro formation" is suggested for this division of the Shenandoah. In central Virginia H. D. Campbell[1] recently subdivided the Shenandoah limestone into several formations, separating at the base a limestone and an overlying series of variegated shale, which he named respectively the Sherwood limestone and the Buena Vista shale. Presumably these are the same subdivisions mapped in this area, but from the data at hand this can not be determined for certain, and since it is known that a large fault and corresponding gap in the stratigraphy occur in the intervening Harpers Ferry area, new names are here proposed for the formations.

Massive, bluish-gray, magnesian limestones, with numerous thin layers and nodules of chert and beds of shale, possibly 2,000 feet in all, compose the next formation. Red and green shales are present in the middle of the formation, and beds of sandy limestone, which in places form low ridges, occur higher in the section; but none of the beds have been traced for any considerable distance. The only fossils which have been found in this portion of the section are those mentioned as occurring in the basal layers and indicating Acadian age. The name "Elbrook limestone," from a town at which the formation is quarried, is proposed.

A change to siliceous sediments with conglomerate, oölite, and red clay, marks the base of the next succeeding formation. The siliceous layers weather to granular porous sandstone, which produces a low ridge and offers another marker in the otherwise uniform limestone section. Conglomerates of rounded pebbles of dense magnesian limestone, imbedded in a matrix largely of quartz grains, indicate an elevation of a portion of the nearby sea bottom into a land area and the erosion of the limestone, the quartz sand coming from a more distant source on the land. Other conglomerates or breccias of flat fragments of thin slabby limestone variously arranged in a matrix of calcareous mud are intraformational conglomerates derived from recently deposited silt broken up by wave,

[1] *American Journal of Science*, Fourth Series, Vol. XX, No. 120, pp. 445–47.

tide, or current action. The thin fragments are often tilted on end, and resemble the "edgewise beds" of Missouri described and figured by Nason.[1] Red clay in crevices and holes of the limestone suggests surface weathering and residual clay filling solution pockets. Oölite is evidence that the water was sufficiently shallow for the waves to oscillate the particles on the sea bottom. For these reasons it is concluded that this horizon represents a break of some consequence in the sedimentation, due to uplift and erosion in this or in some immediately adjacent territory. Since this change is accompanied by the introduction of a different fauna, specimens of which, chiefly trilobites, collected at Scotland, were determined by Walcott as Saratogan (Upper Cambrian), it is regarded as representing the base of the Saratogan. Associated with the conglomerates is a minutely laminated pure limestone with parallel, wavy, dome-shaped, and contorted structures. Horizontal sections of the dome-shaped structure show regular concentric rings, whereas the vertical sections show waves with round tops and angular bottoms, as shown in Fig. 3. No internal structures were observed by which organic origin could be determined, but in a general way they resemble *Stromatopora* and may represent some low form of life which spread out on the sea bottom and secreted minute layers of lime. They are undoubtedly similar to *Cryptozoan proliferum* described and figured by Hall,[2] which occur in oölitic limestone near the base of the Saratogan in New York.[3]

The conglomerate zone, 10 to 15 feet thick, is followed by drab magnesian limestone with the same Saratogan fauna, grading upward into siliceous limestones containing occasional poorly preserved gastropods of Beckmantown age. The formation is estimated to be 2,000 feet thick. Ulrich, who has recently made a careful study of the rocks throughout the Great Valley, regards this formation as stratigraphically and faunally the same as the Knox dolomite of Tennessee, and the name "Knox limestone" is therefore adopted.

[1] *American Journal of Science*, Fourth Series, Vol. XII, pp. 358–61.

[2] New York State Museum of Natural History *Thirty-Sixth Annual Report* 1883, Plate 6 and description.

[3] Walcott, *Journal of Geology*, Vol. XI, No. 3, pp. 318–19.

The Knox is limited above by homogeneous, fine-grained, dove-colored, pure limestone, extensively quarried throughout the Valley. It contains a few leperditia, gasteropods, and brachiopods of Stones River age, and since the rock is lithologically the same as the Stones River of Tennessee, and apparently occupies the same interval, the name "Stones River limestone" is applied here.

Overlying the Stones River are darker and more crystalline limestones, somewhat cherty at the base and interbedded in the upper portion with argillaceous limestone. Fossils are not numerous in the lower cherty beds, but the upper portion contains a large and interesting fauna, referred by Ulrich to the Chazy and Black River. The formation is well exhibited along the edge of the shale belt west of Chambersburg, and is therefore named the "Chambersburg limestone." The thickness of this and the Stones River formation was not determined by the writer. Sections recently made by Ulrich near Greencastle, 8 miles west of Waynesboro, show 400+ feet of Stones River limestone and 1,000+ feet of Chambersburg limestone.

The Martinsburg group.—The calcareous strata are followed by a series of shales and soft sandstones previously called the "Martinsburg shale." At the base are a few feet of dark calcareous shale and thin beds of carbonaceous limestone, transition beds, containing a fauna regarded as Trenton in age. These are followed by dark to gray platy shale, with *Leptobulus insignia*, *Triarthus becki*, and other Utica forms, including numerous graptolites, and it is therefore named the "Utica shale." It is generally intricately folded and crinkled, but the thickness is estimated to be 1,000 feet. Above it are greenish to buff, soft sandstone which is named Eden because it contains a fauna referred by Ulrich to the Eden, and is regarded by him as stratigraphically its equivalent. It has a thickness of about 500 feet. These shales and sandstones form the tablelands rising out of the limestone lowland west of Chambersburg.

STRUCTURE

All the rocks of the region have been folded and highly compressed, and nearly all have acquired a secondary structure. In the mountains the rocks have a marked schistosity, most completely

developed in the soft shales and feldspathic rocks, but even the hardest quartzites have parallel jointing and to some extent are schistose. The strike of the schistosity is parallel to the ridges, and the average dip is 35° southeast. In most cases this is the dominant structure, often producing a banding which closely resembles bedding and entirely obliterates the true stratification. It is not surprising, therefore, that many of the early geologists, mistaking the schistosity for bedding, failed to understand the relations. The stratification can be determined in the *Scolithus*-bearing rocks because it is perpendicular to the worm-tubes, and in the coarser sandstones and conglomerates it is sometimes shown by alternations of coarse and fine material or by color-banding. The dips are thus observed to be usually either vertical or steep to the west. The sandstone series is found to dip away from, and therefore to overlie, the volcanics, and to pass steeply beneath the limestone of the valley along the west front of the mountain. A similar highly inclined sandstone series on the east side of the volcanic rock belt is mentioned by Walcott in his paper on the Cambrian rocks of Pennsylvania.[1] The structure of the mountain belt as a whole is therefore a broad anticlinorium.

East of Montalto.—The general structure of the mountains east of Montalto is a flat-topped, steep-sided anticline, with the east limb not exposed in the area. The ancient volcanic rocks exposed in the low plateau at the eastern edge of the area are overlain by the flat-lying, purple, feldspathic sandstones of Snowy Mountain. These sandstones may also be seen in the mountain north of the volcanic area, beyond Conococheague Creek. Westward the strata bend down sharply, and their upturned edges form Rocky Mountain, one of the few really rugged heights in this area. The shale valley in which the West Branch of Little Antietam Creek has its source is followed by the *Scolithus* sandstone of Montalto Mountain, which dips steeply to the west. At the foot of the mountain soft, calcareous, *Scolithus*-bearing (Antietam) sandstone is followed by gray and mottled limestones, with vertical and steeply overturned dips. Farther out in the valley the limestones are found to be closely folded.

[1] *Loc. cit.*, p. 24.

Northward a minor sandstone ridge forks at an acute angle from Montalto Mountain in strike with the soft calcareous sandstones at the foot of the ridge opposite Montalto. This seems to indicate that the Antietam sandstone is variable in thickness and hardness, as previously stated; but its failure to make a separate ridge at this point may in part be due to shearing along this highly compressed zone. The increased width of the shale valley to the north is due largely to flatter dips. The occurrence of brown iron ore in the residual clays along the mountain front, once so extensively mined in the vicinity of Montalto, has been considered by some as evidence of the existence of a great fault here. Similar ore deposits occur all along the mountain front, however, even around the ends of folds where faulting cannot have occurred, as will be demonstrated below, and are evidently produced by the leaching of iron from the ferruginous shales and sandstone of the mountain rocks and its precipitation, either by humic acid in bogs along the foot of the mountain, or by chemical action with the limestone with which the deposits are usually associated.

The Waynesboro fold.—Northeast of Waynesboro, where the mountain bends sharply to the east, the low hills of the valley are seen to curve first to the east and then to the south, roughly parallel to the offset in the mountain. The rocks of both the mountain and the valley ridges are found to trend and curve in the same direction as the ridges; i. e., the southwest strikes change abruptly to east, and even northeast, and then to the south again. The dips in this curved portion change from 60° W. to 20° S. Beyond, the ridges and the rocks resume their straight southward course for a short distance. It is thus seen that the offset in the mountains at this point is due to a sharp anticline and flat syncline plunging steeply to the southwest, the axis of the syncline passing through Sandy Ridge and Snowy Mountain. The parallelism and low accordant dip of the limestones of the valley and the mountain rocks throughout this fold, and the absence of any stratigraphic break, are conclusive evidence that no fault exists along the front of the mountain at this point.

The East Branch fault.—The East Branch of Little Antietam Creek flows in a limestone valley extending into the mountains

several miles. The limestones strike northeast, approximately parallel with the ridges on the south side, but diagonally across the trend of the sandstone ridges on the north, which terminate abruptly. This condition is the result of a fault cutting off the quartzite beds along the north side of the re-entrant valley and offsetting them several miles to the east. The fault apparently marks the axis of a fold, similar to that just described east of Waynesboro, in which a sharp anticline, followed to the southeast by a deep syncline, was compressed so closely that the anticline was entirely sheared out, and the limestone in the syncline now rests against the edges of the broken quartzite beds.

Big Flat anticline.—Big Flat Ridge, north of the Conococheague, is a broad, flat-topped anticline which to the north, beyond the quadrangle, forms the major part of the mountain range. A line of small knolls, composed of the *Scolithus*-bearing Antietam sandstone and dipping from 50° to 70° to the northwest, skirts the western foot of the mountain. An inner row of higher knobs is composed largely of vitreous non-*Scolithus* rock, the Montalto quartzite member. The upper shale of the Harpers formation is thin in this ridge, and the sandstone member more prominent. Apparently the shale is gradually replaced to the north by sandstone, which becomes the major part of the formation. The counterpart of the line of knobs is found on the eastern side of the ridge, composed of similar rocks and with dips of 45° to the southeast. At the south end of the mountain the same rocks bend around parallel to the southern face and dip 20° to the southwest, abruptly ending the anticline. On the crest of the ridge the beds, where exposed, indicate gentle folds, and over the level surface of the mountain top the rock fragments are chiefly *Scolithus* sandstone, apparently of the Montalto horizon. The deep ravines intersecting the anticline may cut through the Montalto quartzite member into the lower shale of the Harpers, but in no place was the underlying Weverton sandstone observed.

Beyond the end of this plunging anticline the valley rocks for several miles are hidden by wash, but from exposures farther to the southwest they are seen to be intricately folded. Whereas the hard massive sandstone beds of the mountain form one bold broad

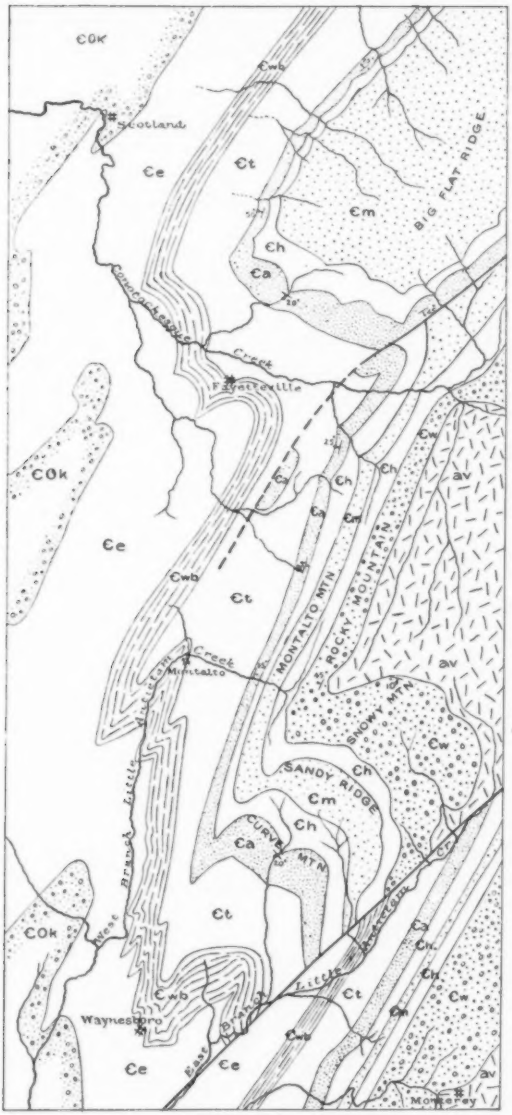

FIG. 2.—Geologic map of South Mountain in southern Pennsylvania, and adjacent portion of Cumberland Valley. *COk*, Knox limestone; *Ce*, Elbrook limestone; *Cwb*, Waynesboro formation; *Ct*, Tomstown limestone; *Ca*, Antietam sandstone; *Ch*, Harpers formation; *Cm*, Montalto quartzite member of Harpers formation; *Cw*, Weverton sandstone; *av*, ancient volcanics.

arch, the limestones around the pitching end are crumpled into numerous close folds, as may be seen on the geologic map, Fig. 2.

Just east of this Big Flat arch the Antietam sandstone, containing *Scolithus* and fragments of *Olenellus*, is crushed to a coarse breccia and cemented by iron. This crushed zone is the closely compressed, faulted syncline between the Big Flat and Montalto arches, and apparently the quartzite of Little Mountain is brought to the surface along this line of fracture by a minor anticline.

Origin of the structures.—It has been shown that the general structure of this part of South Mountain is a flat-topped arch, with the sedimentary beds on the western flank disposed as a steep monocline, dipping away from the older volcanics in the heart of the range, and beneath the limestones of the valley. This simple structure is complicated at several points along its strike by secondary folds, giving rise at their pitching ends to offsets in the mountain front.

The steep, often overturned, dips of the western limbs of the anticlines both in the mountain and valley rocks indicate that the crustal movement was to the west, and that the compressive force at the surface came from the east. This conclusion is also borne out by the schistosity dipping 35° to the southeast. The ultimate force, however, may have acted as a deeper-seated stress from the northwest. According to the theory of isostatic adjustment, the loading of the sea bottom during all of Paleozoic time would produce a deep-seated flowage toward the land. Isostasy need not, however, be depended on to account for such movement, for the thousands of feet of sediments in themselves represent an equivalent sinking of the sea bottom, whether the result of loading or of some independent cause. This landward motion would be transmitted in a certain degree to the overlying sediments, and they would be moved, by a force acting from below and from the northwest, against the consolidated land mass as a buttress, which would produce a resistant force in the opposite direction acting at the surface. The buttress in this case would be the Archean rocks of the Piedmont to the southeast, now partially covered by Triassic sediments. Thus we should have exhibited at the surface structures produced by the resistant stresses from the southeast, i. e. folds overturned to the northwest and schistosity dipping to the southeast.

At the north, opposite Fayetteville, a massive anticline rose to the west of the main axis and barred the way to further movement

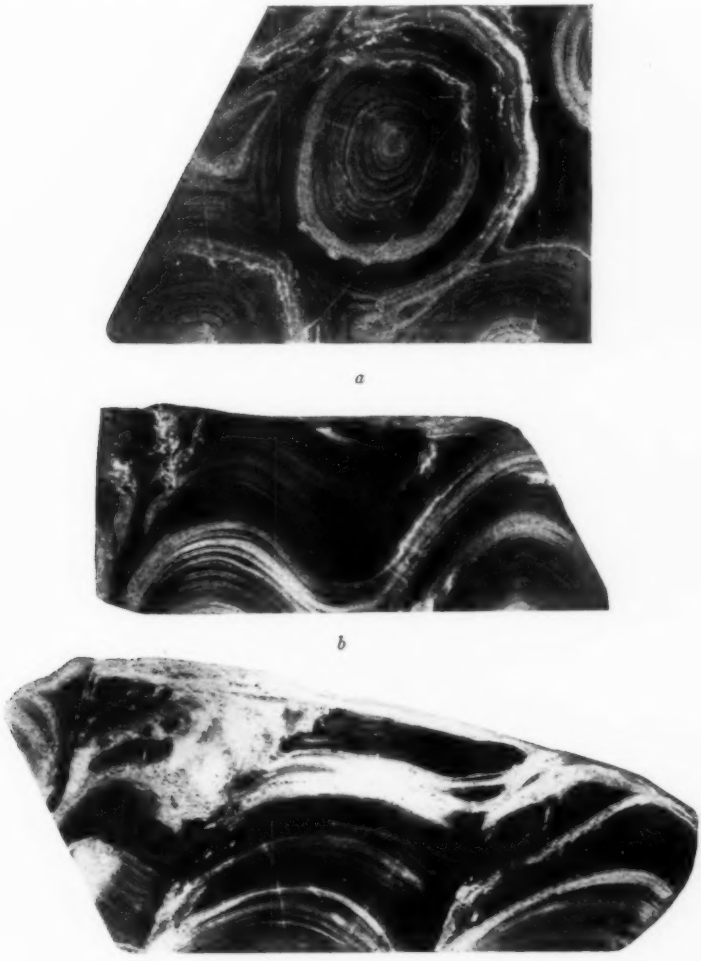

FIG. 3.—Cryptozoan proliferum, from base of Knox limestone west of Fayetteville. Natural size. *a*, horizontal section, under side; *b*, cross-section of specimen *a*; *c*, cross-section of another specimen.

along the main axis in that direction. South of this point, however, by the yielding of the limestones of the valley in close folds, the rocks of the mountains moved bodily to the west, past the end of the anticline, thus causing a deflection of the trend of the axis of the main uplift behind this barrier, as may be observed by the change in direction of ridges on opposite sides of Conococheague Creek.

Earlier views.—The views of earlier writers on the geology of South Mountain are concisely summarized by Keith in his paper on the Catoctin belt.[1] These opinions were somewhat diverse. The two classes of rock composing the mountain were clearly distinguished by them all, and the igneous origin of the schists was generally recognized. The prevailing conclusion of the earlier writers, however, was that the sandstones of the mountain front dip eastward beneath the schists, and are therefore older, and probably Archean, and that a great fault exists along the west foot of the mountain. These views were held as late as 1892 by Lesley, who constantly refers in his final report[2] to the "lower or quartzite conglomerate slate series" and "the overlying feldspathic, micaceous, chloritic series,' thus reaffirming the interpretation of the stratigraphy and structure published in earlier volumes.

In this same year Walcott[3] found fossils in the uppermost layers of the sandstone series in the southeast corner of the area under discussion and in other parts of South Mountain, which, together with stratigraphic observations cleared up the stratigraphy and structure. The sandstone series was observed to overlie the orthofelsites and was proven to be of Georgian age. This view was confirmed, on structural evidence, by Keith in his paper on the Catoctin belt,[4] although he found the structures in the area to the south much more complicated by faulting than they are in this area.

Lesley, in discussing the offsets in the mountain front, says:[5]

> This geographical eschelon arrangement of the South Mountains is a good indication of their geological structure It renders it probable that the strata, whatever may be their age, have been thrown into a series of anticlinal and synclinal waves entirely analogous to those with which the Paleozoic country of middle Pennsylvania have made us so well acquainted.

[1] *Loc. cit.*, pp. 318–20.

[2] Pennsylvania Geological Survey, *Final Report*, Vol. I, pp. 144–46.

[3] *Loc. cit.* p. 24. [4] *Loc. cit.*, pp. 321–23. [5] *Loc. cit.*, pp. 143–45.

Thus far his conclusion is good, but inasmuch as the sandstone series along the mountain front is, according to his interpretation, older than the orthofelsite series, and dips away from the limestone of the valley, he concludes further that

> *A master fault* must therefore run along the northwest foot of the mountains, along the low drift-filled valley of Yellow Breeches Creek [Mount Holly area], in which nowhere can any rock be seen in place, but only a series of brown hematite iron ore deposits, some of them of great size and once extensively mined in open quarry work. The northwest face of the mountain mass is therefore in fact the eroded basset edge of the quartzite series dipping away from the fault. The thickness of the quartzite and conglomerate series may be imagined from cross-section No. 10, laid 2½ miles north of Greenwood [east of Chambersburg], along which for five miles quartzite beds on a prevailing southeast dip are either seen or indicated suggesting a total thickness of 14,000 feet [a partial measure of the throw of the "master fault"].

Walcott accounts for the mountain offsets chiefly by thrust-faulting, as expressed in the following extract:[1]

> My impression is that these offsets [in the mountain front], and also the complicated structure of the mountain, arise partly from folding, but more largely from the westward thrusts of masses of strata along the lines of fault of a low hade. This westward thrusting on the fault plane, complicated by previous folding of the strata, leaves masses of the subjacent, pre-Paleozoic rocks resting, in various places, on different members of the Lower Cambrian series, and also appears to interbed the quartzites and schists of the Cambrian in the schists, eruptive, etc., of the Algonkian.

Keith also holds the view that strike faults have a prominent part in the structure of the mountains, especially along the western border. He shows their presence in the Catoctin belt,[2] and carries them into the area southeast of East Branch of Little Antietam Creek.

CONCLUSION

It has been demonstrated in this paper that the conclusions of the writers quoted above are not applicable to the area here discussed; that thrust-faulting cannot account for the offsets in the mountain front near Fayetteville and opposite Waynesboro, but that they are due to folds plunging steeply to the south, with the strata in unbroken sequence; that along the straight portions of the mountain front the youngest beds of the sandstone series are next to the

[1] *Loc. cit.*, p. 27. [2] *Loc. cit.*, pp. 358–62.

limestone of the valley; that they appear to be in comformable sequence with dips varying from low west to steeply overturned; and that, if faulting occurs along these lines, it is of minor importance. The fault producing the deep re-entrant valley of East Branch of Little Antietam Creek and the corresponding offset of the ridges, a thrust of considerable magnitude, does not follow the front of the mountain, but strikes at an acute angle into the valley. The same is true of the crushed and faulted zone north of Conococheague Creek.

THE CHEMICAL EVOLUTION OF THE OCEAN[1]

ALFRED C. LANE

The paper was suggested by the chemical character of the deeper mineral waters of Keweenaw Point. The fundamental ideas were stated years ago, by T. Sterry Hunt, who called attention to the fact that in the Canadian Paleozoics there is less sodium in proportion to the chlorine than in the present ocean. The same fact is true of the deeper waters, both in upper and lower Michigan. Not only so, but taking the lowest sodium chlorine ratio, which generally comes from the deepest, or one of the deepest, wells found in any water of a given geological horizon, it appears that the older this formation, the lower the ratio. The ratio of sodium to chlorine varies from 0.468 at Big Rapids, to 0.084 near the bottom of the Tamarack Mine.

TABLE I

SODIUM: CHLORINE RATIO IN MICHIGAN DEEP WATERS

Location of Water	Geological Horizon	Reference	$Na:Cl = R$	$\frac{1-1.81R}{1-0.531R}$	$\frac{1-1.81R}{0.648}$
Portsmouth	Base of Pennsylvanian	W.S. 31, No. 251	0.586	.....	.....
Big Rapids	Marshal, mio-Miss.	W.S. 31. No. 278	0.468	0.200	0.234
Midland	Marshal, mio-Miss.	W.S. 31, No. 281	0.284	0.570	0.750
Bay City	Berea, base of Miss.	An. 1901, p. 225	0.350	0.450	0.564
Alma	Traverse, mio-Devonian	W.S. 31, No. 329	0.306	0.490	0.632
Assyria	Dundee, mio-Devonian	An. 1903, p. 108	0.321	0.525	0.673
Mount Clemens	Salina, neo-Ontarian	W.S.31, No. 319	0.304	0.480	0.625
Manistee	Niagara, mio-Ontarian	W.S.31, No. 323	0.236	0.650	0.883
Britton	Niagara, mio-Ontarian	New Kedzie	0.358	0.440	0.544
Whitby, Canada	Trenton, Ordovician	18 An. U.S.G.S. p. 652	0.25	0.630	0.865
Osceola, Wis.	Potsdam, neo-Cambrian	W.S. 114, p. 240	0.214	0.700	.....
Freda, Mich.	Upper Keweenawan	An. 1903, p. 165	0.189	0.720	1.01
Tamarack Mine	Lower Keweenawan	New Wilson	0.084	0.890	1.31
Vulcan Mine	Huronian	Am. 1903, p. 155	0.000	1.000	1.515

The last two columns give the age in fractions of a hundred million years, supposing that none or all of the sodium chloride in the rivers is cyclical.

[1] Abstract of paper read at the Ottawa meeting of the Geological Society of America, December, 1905.

One of the explanatory factors must certainly be that suggested by T. Sterry Hunt, that in river water there is always more sodium in proportion to the chlorine than in the ocean, and that hence the carbonate of sodium, as it may be supposed to be combined, is always reacting with the calcium-magnesium chloride of the ocean water, throwing out calcium carbonate, probably by organic agencies, and leaving sodium chloride in excess instead. Professor Joly, of Dublin, has based an estimate of the age of the earth upon this accumulation of sodium in the ocean, which has been criticised, because of some minor assumptions which do not affect the reason-

TABLE II

ANALYSES OF RIVER WATER

	1. Mississippi River[1]	2. Lake Superior[2]	3. Murray's Average[3]	4. Thousand Tons per in Mile
Si	0.00350	0.00317	0.008370	34.90
Al	0.00009	0.00048	0.001820	7.60
Mn	0.00012	Sr 0.00134	0.001960	4.00
Fe	0.00008	0.00069	0.002180	9.10
Mg	0.00680	0.00278	0.007850	32.80
Ca	0.02950	0.01280	0.034100	142.17
K	0.00230	bare trace	0.002180	9.13
Na	0.01000	0.00318	0.005790	24.10
Cl	0.01610	0.00243	0.003100	12.91
(SO_4) S	0.00960	0.00124	0.004540	18.94
(PO_4) P	0.00013	B tr	0.000140	0.58
(CO_3) C	.....	22.2300	.....	.....
(HCO_3) C	.02160	.....	0.013230	55.28
N (free am.)	0.00016	.....	0.000065	basic N. 0.27
N (alb. am.)	0.000014	.....	.....	basic H. 0.08
Nitrites	.....	.....	.....	.....
Nitrates	0.00023	0.00077	0.00106	(AcidN.) 443
Total solids filtered	0.16750	0.05896	0.10000	762.587
Unfiltered	1.06900			
Loss in ignition				
Organic matter				
Filtered	0.02750			79
Unfiltered	0.07160			

1. C. H. Stone, Analysis of Mississippi River Water, *Science*, 1905, p. 472, with oxygen consumed: filtered, 0.0142; unfiltered, 0.0033; hardness, 10.92; turbidity, heavy (twice averaged); sediment, large; odor, none.

2. Analysis of Lake Superior water, *Annual Report*, Geological Survey of Michigan, 1903, p. 113.

3. Average river water computed from Murray in grams per kilogram or liter.

4. Average river water according to Murray, compiled from figures given by Joly and Chamberlin's *Geology*, in thousands of tons per cubic mile. Multiply by 6.524 to get total yielded in millions of tons per annum.

TABLE III

COMPOSITION OF OCEAN[1]

	1	2	3	4
Na	306.37	1.1400	1.41.80	1.570
Cl	552.17	2.0700	2.55.57	2.850
Ca	11.96	0.0500	0.05.53	0.070
Mg	37.69	0.1400	0.17.43	0.190
C	0.41	0.0020	0.00.19	0.003
S	25.62	0.0900	0.11.87	0.125
K	11.07	0.0400	0.05.02	0.060
Br	1.88	0.0078	0.00.87	0.010
O	52.83	85.7900	.....	118.400
H	.....	10.6700	.....	14.700
	100.00	100.0000	.....	

1. Composition of sea salt—Diltman in Van Hise, p. 942.

2. Composition of ocean—Clarke in Van Hise, p. 944.

3. Bulk of salts in ocean divided by antilog 16 according to Van Hise, p. 944. I do not understand how he gets these figures; they seem to be 1.24 (× antilog 14) greater than column 2, whereas, according to Van Hise's figures, the multiplier should be 1.32×antilog 14.

4. Column 2 multiplied by 1.375 giving weight of salt in units of antilog 16 tons, if the volume of the ocean is 3,200,000 cubic miles.

ing or results materially. If there has been such an accumulation, there must have been such a change in the chemical character of the water as there really appears to be upon careful study of the analyses of deep waters.

If the amount of sodium now in the ocean be N, and of chlorine C, and there is brought in each year by the rivers n, of sodium, and c of chlorine, and if we subtract from n a quantity d to obtain the net increase of sodium after allowing for that blown inland by the breezes or buried in the sediments laid down, etc., and let rd be a similar correction to be applied to the chlorine, then the ratio of sodium to chlorine (let the ratio be R) in the ocean x years ago would be, accepting a uniform rate of accumulation,

$$R = \frac{(N - x(n-d))}{(C - x(c - Rd))}$$

and

$$x = \frac{N - CR}{n - cr - d(1 - rR)}$$

[1] After Van Hise, p. 193.

Substituting in this formula the numerical data used by Joly, one will get Joly's results as to the age of the earth. By assuming appropriate values of R one can assign a date to the burial of any brine.

N and C are reasonably well known. Sir John Murray's estimates, the only ones made as yet, for c and especially n are liable to be seriously in error. The quantity $d\ (1-rR)$ is likely to be a small correction, except in the case of volcanic emanations of chlorine, for in the case of most other allowance r is likely to be pretty nearly reciprocal to R.

Inserting Joly's numerical values we obtain

$$x = \frac{1.41 - 2.54R}{1.57 - .84R - \mathrm{d}\ (1 - rR)}$$

in hundreds of millions of years.

A formula involving a slightly different volume of the ocean may be as exact and is more convenient, for computation, and was used by the author.

A somewhat elaborate discussion of analyses and the probabilities of the case led to the conclusion that, while a similar formula, which was given, could be constructed for any two substances brought into the ocean by the rivers, among those abundant enough to be well determined by analysis the chlorine and sodium were the only ones likely to accumulate, and not be modified seriously in relative proportions even when buried.

Among the difficulties discussed were the high concentrations of the deeply buried waters, and the very low amount of sodium in the Keweenawan, which is by no means the base of the geological column.

The suggestion was made that perhaps the volcanic contribution to the ocean was by no means an unimportant one, and that there had been a continuous emanation of chlorinated water, adding to the volume of the ocean from the very earliest times.

The analyses upon which the paper was based have mainly been published in *Water-Supply Paper* No. 31 of the United States Geological Survey, and in the annual report of the Geological Survey of Michigan for 1903. Tables of analyses, in ionic form, were given for Murray's average river water, Lake Superior, and the Mississippi River; also of the ocean and Keweenawan mine-waters.

A diagram was also shown in which, alongside Dana's geological column (which is proportioned according to his estimates of the lengths of the geological periods), the sodium: chlorine ratio, and computed ages of various brines, were laid off horizontally, which diagram was constructed from Table I.

TABLE IV

(KEWEENAWAN WATER ANALYSES (grams per kilo)

	1	2		3		4
Sp Gr	.....	.....			1.0511	.....
Insoluble silica....	0.0222	.....			.....	.....
Insoluble Fe_2O_3..	0.0127	.....			.....	.....
Dissolved Si O_2...	0.0033	0.00005			.....	.....
Fe Cl_2 ..	0.0045	.....		Mn.	0.5700	.....
Zn Cl_2.	0.0290	.....			.....	.....
Cu Cl_2..	0.0043	.....			.....	.....
Mg Cl_2 .	0.0875	NH_4Cl	2.457	Mg_2 Br	0.2400	.....
Na Cl ..	1.8800		21.009		19.2900	.....
K Cl ...	0.0740		1.595		0.5600	.....
Ca Cl_2 .	3.1380		130.508		44.5100	.....
Ca SO_4	0.0555		0.320		.....	.....
Ca CO_3	0.2480		.....		.....	.....
Loss on ignition...	1.0800		.....		.....	.....
Sum.....					6.517	
Total solids on evaporation.....			154.4115			
Dissolved ions—						
NH_4.....	.....		0.830		.....	.....
Fe.....	0.0020		.....	Mn	0.57	.....
Zn.....	0.0134 + Ni	Ba, Sr	0		.....	.....
Cu.....	0.0022		.....		.....	.....
Mg.....	0.0232		tr		0.03	0.0130
Na.....	0.7400		8.278		7.60	2.7310
K.....	0.0388		0.837		0.30	
Ca.....	1.2496		47.166		16.04	6.3000
Cl.....	3.265		97.963		40.42	15.2287
SO_4.....	0.0392		0.226	Br	0.21	0.0724
CO_3.....	0.1490		0			

1. Is the water from the boiler of the vertical shaft of the Calumet and Hecla Mine, about 5,000 feet deep, but containing more or less surface water, by Heath. See *Annual Report*, 1903, p. 166.

2. Tamarack cross-cut, 4,300 feet deep—A. C. Lane, sampler; F. B. Wilson, analyst.

3. Freda Well, *Annual Report*, 1903, p. 166.

4. Wolverine Mine—seventeenth level—A. C. Lane, sampler; F. B. Wilson, analyst.

THE FOLDING OF SUBJACENT STRATA BY GLACIAL ACTION

FREDERICK W. SARDESON
Minneapolis, Minn.

A number of upthrust folds of stratified rocks subjacent to glacial deposits occur at several places in Minnesota. Formerly they were considered as well-recognized glacial phenomena, and accordingly I took no special interest in them. More recently doubt has arisen[1] as to their origin, and this has led to my making a closer study of some of these occurrences. Proof of their true nature as glacial phenomena can now be given. The folds are more or less regular arches from 2 to 30 feet wide, and half as high as wide. The strata of which they are composed belong to the Galena (Trenton) series, or to other formations in Minnesota, which lie as a rule horizontally throughout their extent. The folds and similar displacements are both exceptional and limited to the superficial part of stratified formation, so that no doubt need be entertained as to their being the result of surface agencies.

For example, three such folds were seen in quarries and gradings at St. Paul, Minn., along the 800 foot terrace which runs on the north side of the river from the city to Fort Snelling. This terrace is a limestone bench nearly cleared of glacial deposits by the glacial River Warren. The surface of the limestone lies now generally within the reach of the winters' frosts—i. e., less than 8 feet deep—and the folds in it either lie within reach of frost or may have been in that position at some time in the past. Their origin might therefore be supposed to be due either to the action of frost in water-filled joints of the limestone, or, on the contrary, to the mechanical action of a glacier. Saturation and drying of the strata might also be supposed to have caused them. It was, in short, difficult to prove which agency had caused them.

[1] H. L. Fairchild, "Ice Erosion Theory a Fallacy" *Bulletin of the Geologica Society of America*, Vol. XVI, pp. 12–23.

Two of the same kind of folds have been disclosed more recently in Minneapolis, and these lie in such relations as to show very distinctly their origin from the mechanical action of glacial ice. Since I am now convinced that the folds seen in other places have, with one exception, not been produced by the action of frost, nor by the saturation and drying of the rock strata, I shall describe, for

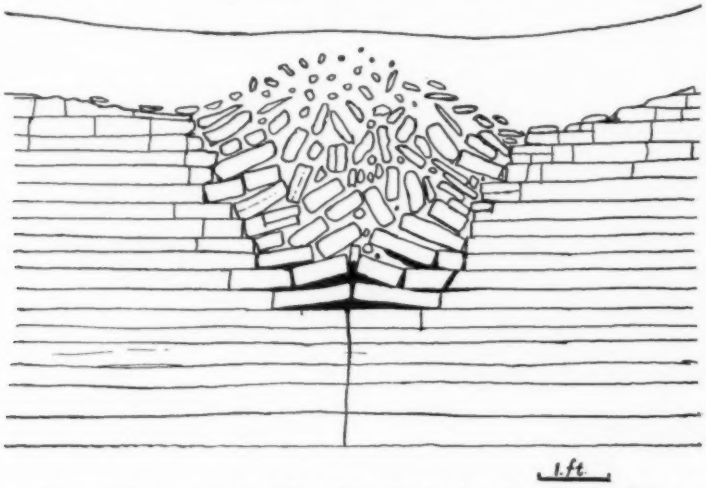

FIG. 1.—Limestone strata upheaved by the freezing of a stream, which now flows under them.

the sake of comparison merely, the one case of undoubted upheaval of a limestone fold by frost and weathering, and then, in particular, the two newly discovered cases of undoubted glacial folding. The case of folding by frost and weathering occurs in the old city quarry at Camden Place, in the northern part of the city of Minneapolis. Here the lowest limestone bed of the Galena (Trenton) series lies near the ground surface, within the reach of frost and humid agencies. A small spring issues from it on the face of a quarry wall, and above the spring the strata and subsoil are seen to be strongly arched (Fig. 1). The origin of this structure is evidently as follows: The stream once flowed on the limestone's surface; annual frosts have heaved the rock-bed so as to let the stream into deeper courses; weathering has aided in loosening the stones and in form-

ing subsoil between them. The folds previously mentioned as seen at St. Paul are dry, and they differ from this one in being more uniform from top to bottom and in the less weathered condition of the stone. They resemble more closely the fold formed by glacial action, which will be next described.

This clearest case of glacial folding occurs at the site of the new lock and dam, No. 1, on the Mississippi River above the mouth of Minnehaha Creek, in the southeastern part of the city of Minneapolis. Here a new roadway is cut down the face of the river's bluff, exposing a fresh section of part of the limestone and shales of the Galena series and of part of the glacial drift. This section of the fold is represented in Fig. 2. The roadway passes the fold twice in descending the bluff in its first case cutting a gravel bed (*I*) and glacial till (*G*) lying over the fold, and in its second cutting obliquely across the fold and part of the undisturbed strata beneath it. From the first cutting the fold can be seen to extend a distance of several rods. The parts represented in the entire section (Fig. 2) are normally:

I.	Glacial gravel	8′	
G.	Glacial till	8′	
S	5. Gray crystalline limestone	0′	8″
	4. Green clay-shale	2′	6″
	3. Gray crystalline limestone	2′	4″
	2. Green clay-shale	0′	4″
	1. Dark crystalline limestone	1′	6″
B.	Massive granular limestone	5′+	

When folded up, the stratified rocks which in their normal position would comprise 3 feet of hard crystalline limestone and 2 feet 10 inches of compact clay-shale, or about 6 feet in all, in their disturbed condition make up 15 feet of broken limestone and shales. The overlying glacial deposits are made thinner than they are normally, as shown in Fig. 2. The limestone strata, *S* 1 and *B*, beneath the fold, are not disturbed.

It is evident from the section that the strata which are locally folded were thrust together, sliding upon the clay-shale layer, *S* 2, and that the upheaval resulted from the fracture and upheaval of the resisting layers. The overthrust on the right or northeast side,

and the thinning of the till sheet over the axis of the fold, are thought to indicate that the fold was made under restraining pressure from on top. Since the folding effects the glacial till (*G*), and the gravel (*I*), is thinned over it, it was evidently made later than the time when the till was deposited, and perhaps later than the deposition of the gravel. A glacier has undoubtedly crept over this place

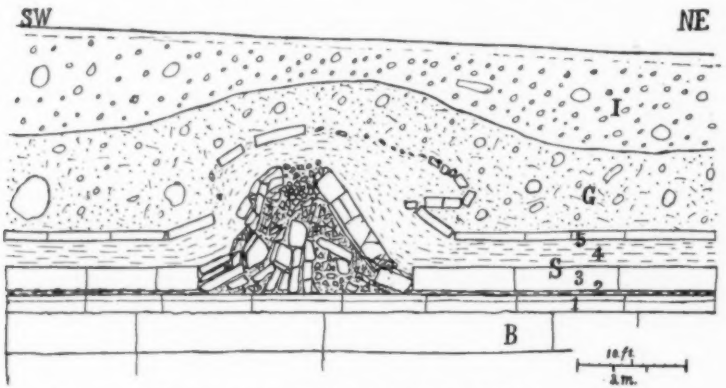

FIG. 2.—Profile of a fold in stratified rocks under glacial deposits.

within this period, as proved by its deposits, although these are absent from this particular spot, presumably because the glacial river Mississippi has cut away the upper sheet of till. Other sections in the same region show the till of the later glacier. It may be assumed, therefore, that glacial ice moving over the till bed, and perhaps over the gravel bed (*I*) gave the thrust that upfolded the limestones and shales at this point.

How the glacial ice could do such heavy crushing of crystalline limestones may perhaps be explained by the friction of the glacier upon the field of gravel, which for a considerable area could accumulate great stress and transmit it to the subjacent strata sufficiently to cause the upper stratified rocks (*S* 3–5) to glide along a clay seam (*S* 2), and thus converge the power of a large portion of the glacier upon a small part of the rock strata. This hypothesis is the more plausible since in some places in this region the gravel bed rests immediately on the stratified rocks.

Why the rock was crushed and folded at this place rather than at any other is not evident in this exposed section. The reason is explained by another case which occurs four miles farther up the river's bluff, in the quarry next to Riverside Park. This case is shown in Fig. 3. The section here shows the following:

G.	Glacial till and soil	about	10′
S	6. Green clay-shale		3′
	5. Gray crystalline limestone		0′ 6″
	4. Green clay-shale		1′
	3. Gray crystalline limestone double stratum . .		2′ 4″
	2. Clay-shale, irregularly laminated		0′ 4″
	1. Dark crystalline limestone		1′ 4″
B.	Massive granular limestone		4′+

Since the till in this section now forms an ancient terrace of the river, it evidently has not its original thickness. Below the till the same rock strata appear as in the other section (Fig. 2) and therefore the parts of Fig. 3 are littered in the same order as those of Fig. 2. The main stratum (*S* 3) appears double here because of a thin irregular shaly lamina within it.

The noteworthy feature in the section is the reversed fault which appears in the top part of the main stratum (*S* 3). The fault is clearly the result of thrust and displacement along an oblique joint. The overlying strata are disturbed by lateral compression and by upward movement of the faulted piece, while the underlying strata are not disturbed. The phenomenon can be explained as the result of glacial friction upon the stratum at a distance from the point of faulting, causing the stratum to move from right to left—i. e., northwest to southeast—as far as the line at which an oblique joint in the rock led to its development of a fault. The fault, as seen on the surface of the rock, which has been cleared of drift in the quarry, runs from northeast to southwest in a reversed curve for about 40 feet. It extends indefinitely farther.

This and the previously described case may be considered as two stages of the same process of folding. Although they were probably not made by the same glacier, at the same time, since the strike of the one is nearly at right angles to that of the other, yet they occur in the same strata under the same till-sheet. Com-

paring Figs. 2 and 3, and noting that the direction of movement is from left to right in Fig. 2, and from right to left in Fig. 3, one can see how upfolding may be begun, and to what extent it could quickly develop in strata subjacent to a glacier which moved over a till- and gravel-covered surface. Why the disturbance ceased just where it did in either of these cases is not evident.

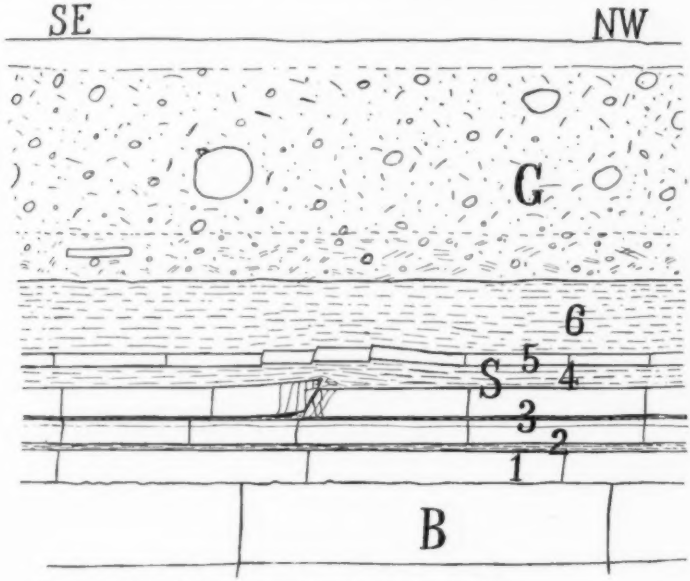

FIG. 3.—Profile showing a thrust fault in strata under till.

I imagine no other cause for the starting of the fold represented in Fig. 2 than that seen in the fault, Fig. 3. The stratified rocks in both places are fresh and not oxidized. In some other cases the cause may have been a little different, especially in the ones mentioned as seen in St. Paul, where there was much evidence of leaching and oxidation by surface water, and where the folds were of limestone strata alone. Those were each immediately over a vertical joint of the rock and contained some residuary clay. From these circumstances it appears that they may have been begun by the sliding of superficial strata toward a widened joint which had

filled with residuary clay, and that the lateral compacting of the clay gave the initial upward thrust. The folds had, however, progressed too far for the conditions of their first stages to be discernible. The presence of residuary clay gave them some resemblance to the case of upfolding by frost as described (Fig. 1).

Regarding the general manner of upthrusting, presumably any weakness of rock structure could serve to determine the point where a folding of strata would begin. The other conditions for such folding are first a seam along which the strata might be caused to slide, and then the force necessary for such movement. This force appears to come through a gravel bed from a moving glacier.

In a former article[1] I have described a similar dislodging of stratified rocks, in a way which caused large masses to be rotated up into the glacier, and thus transported without complete loss of stratification. In the cases now described, the tendency is rather toward complete loss of stratification. One may readily imagine from the appearance of the fold (Fig. 2) that in nearly all such cases the disturbing of the strata when once begun, would end only with complete disruption of the loosened mass and an intimate mixture with glacial gravel and till. Many masses occur in the drift of this region which consists largely of crushed stone and shales with the colors and characteristics of the known stratified rock, but without the stratification or the fossils preserved in them.

[1] *Journal of Geology*. Vol. XIII (1905), p. 351.

THE POSSIBLE GRANITIZATION OF ACIDIC LOWER HURONIAN SCHISTS ON THE NORTH SHORE OF LAKE SUPERIOR

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The Michipicoten and Pucaswa areas on the north shore of Lake Superior present the apparently extraordinary anomaly of containing a conglomerate well supplied with characteristic granitic pebbles, and of exhibiting no older granitic rock of similar structure from which these pebbles could have been drawn. There are, however, of earlier age, acid schists and gneisses of probable igneous origin, and apparently of like chemical composition, though of different structure from these granitic rocks. I would suggest the possibility of the derivation of the granitic pebbles in the conglomerate from a preexisting rock of like characteristics, of which the granite which cuts the conglomerate is the regranitized equivalent. By a regranitized rock I mean one which, originally a granite, quartz-porphyry, or other rock of similar chemical composition and origin, has by metamorphism been altered into an acid gneiss or schist, and subsequent to the metamorphism—or perhaps in part during the metamorphism—recrystallized back into a granite. From our present knowledge of the origin of granite, this recrystallization cannot definitely be said to be refusion, and regranitization is perhaps a more correct and exact term. The original granite, the source of the granitic pebbles, may have been the plutonic equivalent of the rock from which the acid gneisses and quartz-porphyry or felsite schists were derived. It is possible that the gneisses may represent the metamorphic remnant of the original granite.

The Michipicoten Mining Division, which contains an area of some 5,000 square miles, is part of the District of Algoma, in Ontario, and is situated on the northeastern shore of Lake Superior, between latitudes 47° 30′ and 48° 30′. The division was first set apart by the government of the province of Ontario on account of the aurifer-

ous quartz veins which it contains, though it has within the last few years become more important as an iron-ore producer. One mine—the Helen—exports more ore annually than all the other iron mines in Canada put together. Lying within the boundaries of the division is the Michipicoten Huronian area, and to the southwest of the division, and in part within it, is the Pucaswa Huronian area, separated from the Michipicoten area by granite of later age than either.

The Michipicoten Huronian rocks constitute a band from four to twelve miles in width, which extends northward from a point a few miles south of Point Gargantua, on the Lake Superior Shore, to a point about 14 miles south of the main line of the Canadian Pacific Railway. From this point an arm extends both east and west. The western arm, which is the longest and most important, stretches westward from the Magpie River, which may be taken as the center of the north-and-south arm, for a distance of about 40 miles, where it is cut off by granitic rocks. The eastern arm extends eastward from the Magpie River for about 25 miles, and is intercepted by granitic rocks in the neighborhood of Dog Lake. South and southwest of the western arm lie small patches of Huronian rocks which compose the Pucaswa area. The Pucaswa[1] area would naturally be included within the Michipicoten area, because of the similarity in the lithology of each and on account of their proximity, were it not that the Pucaswa Iron Range is quite separate and distinct from the Michipicoten Iron Range in geographical position, and differs markedly in structural features.

The boundaries of the Huronian rock in both the Michipicoten and Pucaswa areas are extremely irregular, but everywhere the bordering rocks are composed of granite or rocks of allied petrographic species. The outer boundary is formed by granitic rocks which are apparently part of the great Laurentian acid eruptive complex of central Canada, which extends northward to within 60 miles of Hudson Bay, and southeastward to the original Huronian area of Logan and Murray—a distance of 120 miles. The inner boundary of the Michipicoten area is an immense granitic batholith with principal dimensions of 19 miles from north to south by 28 miles

[1] In the paper by the writer in the Bureau of Mines *Report* for 1905 the Pucaswa area is called the North Michipicoten area.

from east to west. This batholith is joined to the main part of the acid eruptive complex by a narrow band of granite, which separates the Michipicoten Huronian area from the Pucaswa Huronian area. Another off-shoot from the batholith further divides the Pucaswa area.

The oldest rocks visible in both the Pucaswa and the Michipicoten areas are the so-called Lower Huronian. Above these lie Upper Huronian rocks which, though somewhat rare in the Pucaswa area, have abundant outcrops in the Michipicoten area. Cutting both Lower and Upper Huronian are granites and allied rocks, which have frequent outcrops in the shape of bosses and dykes, within the limits of the Huronian rocks proper, and which have also already been mentioned as forming the boundaries of the Pucaswa and Michipicoten areas. Piercing both the Huronian rocks and the granites are basic igneous rocks of somewhat varied lithological composition, which are very probably Keweenawan.

The Michipicoten Lower Huronian may be subdivided into two divisions—the Helen Iron Formation and the Michipicoten schists. The same rocks in the Pucaswa area may be similarly resolved into an Iron Formation and schists. The Iron Formation in the Michipicoten area and in the Pucaswa area may be regarded as the only definite horizons within the Lower Huronian of the areas. Above and below these formations lie the schists. In the Michipicoten area, and particularly in that part which lies west of the Magpie River, a very close connection between the Upper Huronian rocks and the Helen Formation is observable. The latter, generally, very closely underlies the Doré Formation which in Michipicoten makes up the Upper Huronian, but in some parts of the area thick masses of schists intervene between the Helen Formation and the Doré Formation, indicating either an unequal denudation of the Lower Huronian previous to the deposition of the Doré rocks, or otherwise an unequal deposition of volcanic material after the Helen iron-bearing rocks have been laid down. In some places the width of the Helen rocks appears to diminish, and at the same time there is a relative increase in the amount of schist which seems to suggest that in these parts of the area, toward the close of Lower Huronian times, chemical and aqueous sedimentation was overpowered by volcanic

deposition, whereas elsewhere the former still continued. In the Pucaswa area no such close relation between the iron formation and the Upper Huronian is apparent.

The rocks of the Helen Formation consist of rusty, ferruginous, banded cherts, banded jaspers, banded magnetic cherts, pyritic cherts, sideritic cherts, and various grüneritic, actinolitic, and hornblendic schists, resulting from their metamorphism, together with phyllites, sideritic arkoses, and possibly quartzites. The Iron Formation in the Pucaswa area consists of similar rocks, though sideritic cherts are rare or wanting, and magnetic, banded chert is the most common iron-bearing rock, whereas in the Michipicoten area rusty, non-magnetic, banded chert is the prevailing species.

The schists of both areas comprise chloritic schists, mica schists, hornblende schists, carbonate schists, quartz-porphyry and felsite schists, schistose agglomerates, and amphibolites. All of the schists are intensely sheared, and some of them, particularly the finer-grained varieties, are so evenly laminated that they very closely resemble, and probably actually are, phyllites. Quartz-porphyry schist, a nacreous sericitic rock containing blebs of glassy quartz and sometimes gneissoid, very frequently borders the iron formation in the Michipicoten area, and carbonate schists are also often in close connection. Apart from this somewhat general definite position occupied by these two schists, no exact horizons are held by any other of the Lower Huronian schists.

The Upper Huronian in the Michipicoten and Pucaswa areas consists of the Doré Formation, comprising conglomerates, agglomerates, slates, and tuffs—the conglomerates being the commonest, most significant, and most characteristic. The Doré conglomerate is a very much mashed rock, with a fine-grained chloritic matrix, containing within it rounded fragments of pre-existing rocks of all sizes, from those scarcely visible to the eye, to others a foot or more in diameter. The ground-mass is exceedingly schistose, and the cobbles and pebbles included in it are all more or less elongated parallel to this structure. The harder pebbles show only flattening, parallel to the longer diameter, while the softer pebbles are often so attenuated that they resemble long narrow ribbons, or else are so thoroughly comminuted as to be indistinguishable from the matrix proper. The

pebbles are of granite, quartz-porphyry, felspar-porphyry, felsite, of various cherty rocks derived from the iron formations of the Lower Huronian and of schists and phyllites. Of these perhaps those which stand out most prominently, and which are of most general occurrence, are of the granite rocks, and more especially of a light-colored grayish or pinkish and somewhat porphyritic granite. Sometimes pebbles are almost or entirely wanting, and then the conglomerate passes into the Doré slate—a somewhat rare phase of the Doré Formation, but occurring at several points, notably at the mouth of the Dog River. The Doré agglomerate is also rare, but occurs prominently at several points in the northern part of Michipicoten. It is a somewhat fine-grained chloritic or sericitic rock, containing sometimes a great many, but generally a very few, fragments of rocks, usually of the same chemical composition as the ground-mass, but more coarse-grained, and very frequently porphyritic. It is occasionally with difficulty distinguishable from the water-formed rock. When without fragments it becomes the Doré tuff—a form in general of very unusual occurrence.

The Post-Huronian acid eruptives consist of granites, felsites, syenites, and acid porphyries. Excepting toward the contact with other formations, the porphyritic or felsitic phase is rare, and by far the commonest species, both in the smaller bosses and in the main masses, consists of an even and medium-grained granite of light pinkish color. Though always weathered, it is often remarkably fresh considering its antiquity. It is a much-sheared igneous rock, but not so intensely so as are the igneous rocks which form so prominent a part of the Lower Huronian schists.

That these acid eruptives cut the Huronian rocks all along the line of contact, and are hence later than these rocks, seems almost undoubted, and though outcrops are often poor, owing to the quantity of drift or the thickness of vegetation, still the eruptive contact of the granite with the Huronian rocks is excellently shown in many places. In the compass of this paper no detailed account of many interesting contacts between the Huronian and the granitic rocks can be given. Several representative instances may, however, be cited. Very many points of contact were seen in which the irruptive nature of the granite into the Lower Huronian schists is apparent. Perhaps

the most interesting observed is that seen north of Lake Charlotte, an irregular sheet of water about two miles long, lying within an embayment in granitic rocks just north of Kabenung Lake, and within a few miles of the Dog River. The rocks exposed along the cliffs which flank the northern shore of the lake consist of rusty and sometimes banded cherts, with quartz-magnetite, hornblendic schists and epidote schists, which represent metamorphosed Helen Rocks and Michipicoten schists. A short distance north from the shore, and interstratified with the metamorphic schists, are narrow bands of a light-colored felsite and of coarse-grained quartz-porphyry. Northward from the lake shore these sheets of acid igneous rock increase in width, become more granitic, and are of more frequent occurrence. Moreover, they are often joined one to the other by narrow apophyses of similar rocks. About one half-mile north from the lake granites alone are seen, though occasional small inclusions of schist are of somewhat common occurrence within them, especially close to the contact. Immediately south of the "final contact" the schists are so much metamorphosed that they consist almost entirely of epidote and similar metamorphic minerals, or else are so dense and fine-grained that they are indistinguishable from a hornfels. The granite is of the usual medium-grained, light-pinkish type, and, though distinctly sheared, is not perceptibly laminated, and so could hardly be called gneiss. This granite is apparently part of the great area of acid igneous rocks which stretches northward to within a few miles of Hudson Bay.

An excellent contact between the granitic rocks and the Helen Formation is shown at Mount Raymond, one of the most prominent hills in the Michipicoten area, and which lies just west of Paint Lake and within a mile of the Frances Mine. At this point the Helen Formation is cut by a wide dyke of porphyritic granitic rocks, which forms the most prominent part of Mount Raymond. The iron-bearing rocks are metamorphosed into actinolitic and grüneritic magnetite schists. Contact deposits of impure magnetite occur close to the border of the dyke, and a wide vein of quartz, which is decidedly pyritous and slightly auriferous, has developed within the adjoining rocks. Compared with the intense metamorphic effect exerted by this granite, the decided lack of visible metamorphic

influence generally exercised by the granite, cutting the iron formation in the Pucaswa area, stands in very marked contrast. For instance, the iron formation there is intruded by a huge granitic batholith on the eastern branch of the Pucaswa River, about four miles above its confluence with the western branch. The eruptive contact is abrupt and decided, but the iron formation, which consists of banded magnetic chert, is relatively practically unaltered. The granite is bright red and somewhat coarse-grained, though of even texture.

Visible contacts between the Upper Huronian and the intruding granites are rare as compared with those with the Lower Huronian. This is due probably to the much smaller surface area occupied by the Upper Huronian rocks. There is a good contact showing distinctly the eruptive relations of the granite on the southern shore of Lake Charlotte. Another is on the western shore of Western Lake Kabenung, and still another, and one which is perhaps better shown than either of the others just given, on the shore of Lake Superior, near the mouth of the Doré River.

Somewhat interesting is the geologic section exhibited along the Lake Superior shore from Otter Head eastward. Here the ceaseless washing of the waters has kept the rocks well exposed, and the relations existing between the different formations is easily observed. At Otter Head the rocks, named in order of their age, consist of small areas of evenly banded gneiss, ordinary light-reddish granite, coarse-grained pegmatite, quartz and calcite veins, and dykes of basic igneous rocks. The gneiss is composed of alternating bands one-quarter of an inch and less in width, of dark-colored minerals, chiefly biotite, and similar bands of light-colored minerals, chiefly orthoclase, oligoclase, and quartz. There is apparently not much differentiation into laminæ of the felspar minerals and quartz. The light-reddish granite, which is the prevailing rock, is exactly similar to the Post-Huronian granite described above. The pegmatite, consisting chiefly of large individuals of microcline, orthoclase, plagioclase, quartz, and biotite was probably formed as the result of the action of steam acting upon the hot granitic magma, either during or immediately following its intrusion. The veins are later than either granite or pegmatite, but probably owe their origin to the circulating thermal waters, which followed, and were the result of, the granitic intrusion.

Eastward from Otter Head the inclusions of gneiss appear of finer grain, though always very evenly banded. Gradually these inclusions become more and more common and widen into definite bands, alternating with areas of granite, and more closely resemble the ordinary types of schist. Sometimes the bands of schist are joined to each other by strips of granite. Finally, at about nine miles east of Otter Head, at the prominent point just east of Richardson's Harbour and about four miles west of the mouth of the Pucaswa River, schists alone appear, and are the prevailing rock as far as Ganley's Harbour.

Now, the points which I wish to emphasize are these:

1. A prominent part of the Lower Huronian schists is composed of felsite and quartz-porphyry schists which have sometimes a gneissoid appearance.

2. An Upper Huronian conglomerate contains many granite, quartz-porphyry, and felsite pebbles which are unlike the Post-Huronian acid eruptive rocks. The pebbles of quartz-porphyry and of felsite were probably derived from flows of quartz-porphyry and felsite, now represented by their metamorphic equivalents, the quartz-porphyry and felsite schists. No rock earlier than the conglomerate at present outcrops from which the granite pebbles could have been derived, unless it is the acid gneiss.

3. Immense masses of granites and other acid eruptives cut the Huronian, and are hence later than these rocks. These granites form at least a very prominent part of the acid-eruptive complex, known as Laurentian. Contained as inclusions, sometimes of considerable size, within these acid eruptives, are earlier acid igneous rocks which are typical gneisses.

May not the areas of gneiss be of the same age as the Lower Huronian, and represent merely an intensely metamorphosed felsite or quartz-porphyry, or the deep-seated equivalent of these rocks? Again, is it not possible that the granite pebbles which occur in the Doré conglomerate were derived from a rock no longer existing, but of which the Post-Huronian granite is possibly the regranitized equivalent? Of this Pre-Upper-Huronian rock it is possible that the small patches of gneiss within the Post-Huronian granites are the metamorphosed remnant.

My reasons for thinking that the gneiss areas within the Post-Huronian eruptives are of the same age as the Lower Huronian schists and not earlier (as was the original idea of Sir William Logan and the earlier Canadian geologists) is perhaps a negative one, namely: there is absolutely no evidence of an unconformity between the gneisses and the schists.[1]

Of course, the gneiss may not be, as I suggest, a highly metamorphosed granite, or rock of similar lithological composition and origin. It may be a metamorphosed aluminous sediment, but, judging from the extreme rarity of rocks of such character in the Lower Huronian, this hardly seems likely, though dynamic agencies competent to cause regranitization of Lower Huronian acid eruptives may with considerable justice be considered capable of utterly destroying the identity of water-laid sediments.

Since there are no granites now outcropping similar to those exhibited by certain of the pebbles of the Doré conglomerate, it stands to reason that the granite from which they were derived must either be entirely covered by more recent rocks, or else have altered its state. The former hardly seems likely, because the area is large, and the granite pebbles of this particular sort occur everywhere within the Doré conglomerate. In favor of the second hypothesis—namely, a change of state—it may be said that wherever gneiss and granite areas occur together (which is very frequently the case) there seems to be some slight evidence that the latter is derived from the former. The evidence consists in a peculiar ragged, though sometimes gradual, transitional contact and in the numerous dykelets of granite which ramify through the smaller inclusions of gneiss. It may be objected that this contact is simply one characteristic of any eruptive contact between granite and gneiss. It is of course not my contention that the contact is not an eruptive one, but simply that the granite may be derived from the gneiss. A somewhat homely illustration of a similar phenomenon in nature to that of regranitization may be observed in the recrystallization of ice so frequently seen on the surface of a glacier. Here one may often find a very much banded mass of ice—the banding being due to compression—

[1] According to the International Committee, these schists would be called Keewatin. It will be seen that the geology as sketched in this paper is slightly different from that given by the committee.

veined and slashed with irregular and lensoid areas of more coarsely crystallized ice which show no banding, and represent small crevasses or irregular holes filled with water derived from the melting of the banded ice, and subsequently frozen. What little has been done by the writer seems, however, to prove the hypothesis. It is chiefly in the hope that microscopic and chemical work will be undertaken on this interesting problem, in a careful and systematic way, that these suggestions are now made.

If the theory which is here proposed with regard to the origin of the granites is correct, the geological history of the Michipicoten and Pucaswa areas may be briefly summed up as follows: First, were laid down the series of acid and basic volcanics, with the sedimentary phyllites and iron-bearing cherts, which compose the Lower Huronian on some pre-existing floor, of whatever character that may have been. These were gently folded, and in the consequent synclines were deposited the conglomerates and slates of the Doré Formation. Evidently volcanic activity continued during Upper Huronian times, allowing the deposition of the Doré agglomerates and tuffs. Succeeding the laying down of the Upper Huronian, both Upper and Lower Huronian rocks were intensely corrugated. During this corrugation, and in the main as the direct result of it, came the regranitization of the Lower Huronian acid igneous rocks, which must have existed in quantities largely predominating over all other rocks, and the consequent intrusion of vast masses of granites and allied rocks.

THE IRON CONCRETIONS OF THE REDBANK SANDS

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In the accompanying illustrations (Figs. 1–4), reproduced from photographs, are shown forms of iron concretions which seem to deserve notice alike for their peculiar structure, great length, uniform orientation, and effect on local topography.

These concretions are to be found in immense numbers in the Redbank sands of Monmouth County, New Jersey, a formation which is here a quite structureless bed of loose, rather fine quartzose sand about 100 feet thick, generally red in color from the decomposition of glauconite formerly disseminated through it. The concretions are most numerous near the upper part of the formation, and occur as isolated individuals imbedded in the sand, as well as more or less densely packed in groups.

The primary type of these concretions is a very long, more or less regular, hollow cylinder, which is generally straight and of unvarying diameter, but which sometimes tapers very gradually and may be of indefinite length. Single tubes have been observed which were more than 20 feet long, but it is impossible to remove unbroken such great lengths from the sand in which they are imbedded, owing to the occurrence of transverse cracks which divide them into irregular segments. Fig. 1 is from a photograph of such a segment; the diameter of the tube is 1½ inches. The smallest tube yet observed had a diameter of ¼ inch; the largest tube of *circular* cross-section so far seen had a diameter of nearly 1 foot. The interior of the cylinder is generally filled with sand differing in no respect from the sand without; the wall of the cylinder is merely the ordinary material of the sand-bed, cemented together by iron oxide. While the cross-section of the cylinder is often circular, more frequently it is quite irregular. Still more frequently the concretion is not a closed tube at all, but a corrugated sheet.

Besides simple tubes like that shown in Fig. 1, there are the poly-

chambered types represented in Figs. 2 and 3. Fig. 2 has two unequal and somewhat dissimilar chambers. Fig. 3 shows an end view of a fragment of a three-chambered specimen. In Fig. 5 are shown cross-sections of a number of selected specimens. Fig. 6 is a sketch of the projecting ends of a group of concretions as they appeared in the bank of a railroad cut. Fig. 4 is from a photograph of a bluff in the Highlands of Navesink also showing projecting ends.

In the compound concretions there is usually one primary chamber which is more or less accurately circular in cross-section, and sometimes more than one. The cross-sections of the secondary or parasitic

FIG. 1

chambers are only arcs of circles. It is in fact a notable characteristic of all these concretions, of whatever dimensions or however otherwise irregular, that they show in cross-section practically no other lines than greater or smaller arcs of circles.

As may be seen from Figs. 5 and 6, the number of secondary chambers in a single specimen may be large. Often in a compound individual the ratio of the dimensions of the primary and secondary chambers is rigidly maintained throughout its observed length, but this is not invariable. Frequently a secondary chamber will end abruptly in a *cul-de-sac;* just as frequently it will diminish gradually until its wall merges imperceptibly with the wall of its primary, so that a concretion which is compound at one end may dwindle down to a single primary tube at the other.

A noteworthy but puzzling feature is the fact that, without observed exception, these concretions all occupy a horizontal position, and lie with their longer axes parallel to the strike of the formation, which is

E. N. E., the dip being slight. In some exposures they are seen to occur in parallel zones which are considerably inclined to the normal dip of the strata in this region. As noted above, their distribution through the sand is, in general, irregular. In some large areas they appear to be totally absent, and occur but sparsely in others. In still other areas they are found in crowded aggregations containing an enormous number of individuals, all having the characteristic orientation. Where the concretions lie thickly crowded together, this common orientation gives them an appearance suggestive of great piles of cord-wood partially covered with sand. Such aggregations, which

FIG. 2

are often elongate in the same direction as the concretions themselves, are locally so numerous and large as to impress a peculiar stamp upon the topography, as they serve to protect the loose sand beneath from erosion; the resulting uniformly oriented hills of circumdenudation have somewhat the shape of drumlins. Such hills are numerous on the outcrop of the formation in the eastern part of Monmouth County.[1] The most interesting specimens are not usually found in these situations, as the abundance of iron has led to a thickening of walls and a running together of outlines. The best ones are to be obtained where the glauconite was sparingly disseminated, as in the large cut on the New York & Long Branch Railroad one mile west of Redbank. In this and many other localities the concretions may be dug out of the sand with no other implement than the bare hand; the interior filling may be removed by shaking, or with the aid of a straight stick.

[1]See Sandy Hook Sheet, U. S. Geological Survey (topographic map) south of Eatontown and thence east to Long Branch.

If the removal of the interior filling be cautiously effected, best with the help of a gentle stream of water, there may sometimes be seen fragile, calcified, arborescent forms which ramify through the concretion in complete disregard of the interior partitions, and which are sometimes, but not often, preserved beyond the outer periphery. The dotted lines across two of the cross-sections in Fig. 5 indicate such arborescent forms. They are doubtless fossil stems of plants which were evidently present in the sand before the concretions were formed, and owe their preservation within the concretions to the exclusion of the under-

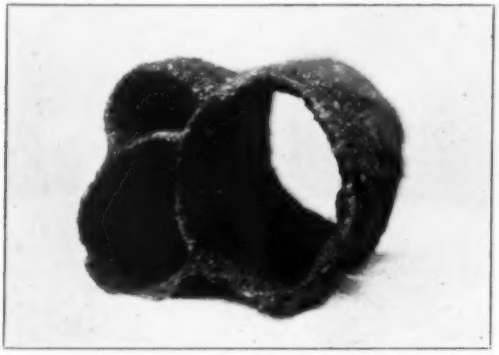

FIG. 3

ground circulation, which has no doubt in most cases removed by solution the parts not so inclosed. If this be the true interpretation, their presence is significant as showing that organic matter was formerly more abundant in the sand, yet they make it exceedingly difficult to believe that these concretions are fossilized remnants of elongate forms of animal or vegetable life, since it is inconceivable how such forms could have inclosed these calcified plants (if such they be) in the manner observed; besides, they bear no resemblance to any known form of life.

Neither is there any reasonable probability that they have resulted from the filling of cracks and subsequent hardening of the filling material. In the first place, they are found in loose sand, which is certainly not a material in which to expect cracks of any kind; in

the second place, the formation of long, straight, horizontal, tubular cracks, or such systems of cracks as would be necessary to give the observed forms to the compound concretions, would be a mechanical marvel under the most favorable circumstances. They are clearly not of stalactitic origin. The Redbank formation is ideally porous; where the concretions display their most typical characteristics the formation does not now, at any rate, possess any structural feature which may have served to guide convection currents. All the evidence

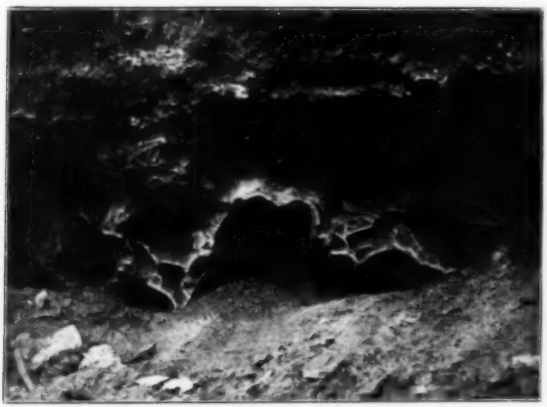

FIG. 4.—Bluff in the Navesink Highlands, showing irregular tubes and corrugated sheet.

obtainable seems to show that the material which supported the growth of the concretions was transported to them by diffusion rather than by convection. Transportation by diffusion here refers to movement of dissolved matter in obedience only to the molecular activities of the substance in solution, while transportation of the same by convection implies a bodily movement of the solution in a determinate direction. The distinction is important in this connection, since if water currents, along with other mechanical agencies, are denied any part in the formation of these objects, they must be regarded as an expression of a molecular tendency of the cementing material.

The evidence in favor of transportation by diffusion is clear and

positive. Where the concretions are absent the ferruginous coloring-matter is in general more or less evenly distributed through the sand; in the vicinity of the concretions the red color is much less pronounced, and may even disappear altogether, leaving the sand clean and white. This at least goes to show that the supply of cementing material was local. Further, many of the isolated concretions, compound as well as simple, lie in sheaths of pure white sand, which they have decolorized as decaying roots might have done. Fig. 7 illustrates a phenomenon often observed in the Redbank formation. There is here shown a segregation of the iron into more or less parallel bands, which locally give the sand a prominent but deceptive appearance of being finely stratified. However, the bands anastamose in a manner which shows that they are not the result of ordinary processes of bedding. The sand of the light bands is poorer, that of the dark bands richer, in iron than sand where segregation has not occurred. The iron oxide in the dark bands is sufficient in amount to occasion differential weathering, but real cementation has not yet taken place; the sand is still so loose that it may readily be excavated with the bare hand. These segregations probably represent a first concentration of the iron by the mutual attraction of like particles. In the sand-bank not far from where the photograph was taken is a large nest of concretions which have absorbed to themselves the iron of all the bands in their immediate vicinity.

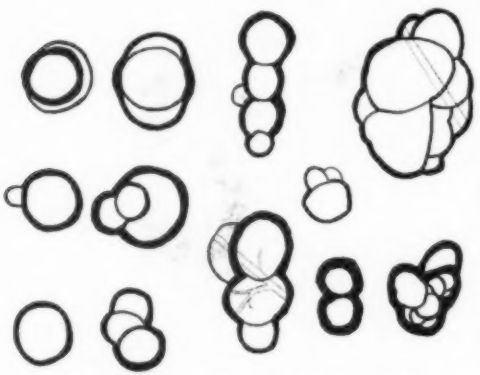

FIG. 5.—Cross-sections of selected concretions.

It is not maintained that convection currents have never circulated through the sand, but it is clear that they must have been quite subordinate when and where the concretions were actively forming.

Finally, a study of the interior structure of numerous compound

concretions has shown relations for which the author confesses his inability to offer explanations based on hypotheses involving fortuitous mechanical circumstances, or possible modes of circulation of water containing the iron in solution. There is among all the phenomena associated with these concretions but one, in producing which mechanical influences can be suspected of having played a tangible part. This is the noteworthy parallelism of their longer axes with the strike of the formation, which suggests that shore currents or waves, acting parallel to or impinging upon the ancient Cretaceous shore, may have sorted into some definite arrangement the material the decomposition of which was later to furnish the cementing bond of the concretions. But the influence of waves or currents must have stopped with the action requisite to govern the orientation of the concretions, and could have played no further part in giving them their observed characteristics.

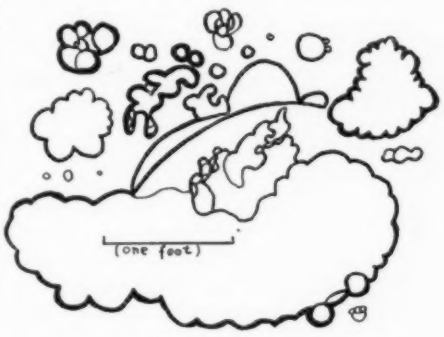

FIG. 6.—Sketch of the ends of a group of concretions seen in a railroad cut.

The author is therefore inclined to the hypothesis which regards these objects as forms proper to the cementing material, which will, under proper circumstances, be assumed in obedience to impulses residing in its molecules. There is evidence tending to show that these concretions have a fairly definite morphology. In many cases it is possible to show with great probability that the various tubes of the polychambered individuals were not synchronous in their origin. In Fig. 8 is given a generalized cross-section of a three-chambered concretion. The relations shown are thoroughly typical. It will be observed that only one—the largest—of the chambers, *A*, is really cylindrical in cross-section; the next largest, *B*, has the outline of a segment of a circle which is cut by the circle *A;* the smallest, *C*, has the outline of a segment of a circle cut by both *A* and *B*. From these relations, and from the relative thickness of the exterior walls and

interior partitions, the history of the concretion is inferred to be somewhat as follows: The concretion probably consisted at first only of the tube *A;* in this condition it must have resembled the concretion shown in Fig. 1. As to what induced the formation of this tube, the concretion itself affords no direct evidence. It may be presumed that, once formed, the wall of the tube was thickened by addition of material chiefly from the outside, and that the rate of addition was practically the same at all points on the periphery. When the wall of *A*

FIG. 7.—Sand bank in Long Branch, showing tendency of the iron (originally disseminated as glauconite) to segregate into anastamosing bands.

had attained the thickness represented by *a*, the arched chamber *B* barnacled itself on *A;* the arch *a*, thus cut off from outside supplies of material, suffered an arrest of growth. The concretion was now two-chambered, like the one shown in Fig. 2. By the time the exterior wall of *B* had attained the thickness of *b*, that of *A* had reached the thickness of *c*. A second parasitic chamber, *C*, was then arched across one of the sulci between *A* and *B; b* and *c* were thus cut off, and their further growth prevented while the exterior walls of the concretion, as it now appears, were taking on their present proportions. The existence of still more complex individuals, in which analogous relations between the several chambers and their walls obtain, shows that the process need not stop with the formation of a three-chambered concretion, but may be continued indefinitely. It is possible to col-

lect any number of suites of specimens having from one to a dozen chambers in which the order of the formation of the different arches may be made out with reasonable certainty. It will be observed that for each new chamber added to the concretion, a new curve is added to its outer boundary, so that in the more complex individuals this boundary becomes exceedingly tortuous.

The uni-chambered tubes of very large and very irregular cross-section, such as those shown in Fig. 6, are to be accounted for under two suppositions. The general appearance of their walls suggests that they were originally very complex individuals which had been built up in the regular way—i. e., by successive additions of secondary chambers—but which have lost their interior partitions through resolution. While this explanation of their origin has a certain plausibility, it is not regarded as the correct one. It is more likely that we have to recognize here the results of a process analogous to, if not identical with, the familiar "twinning" by which the different parts of a crystal may be oriented in contrary ways.

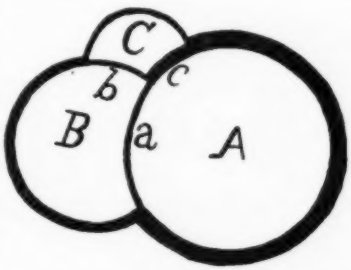

FIG. 8.—Diagrammatic cross-section of a three-chambered concretion.

If it be granted that the molecular tendencies residing in the cementing material be competent to cause it to assume the cylindrical form, it may be taken for granted that the cross-section of the young concretion will be an arc of a circle before it becomes a full circle. It is well-known that in the process of crystallization growing crystals are not always guaranteed against twinning; the molecular forces which govern crystallization are capricious. In the case of the young concretion there is no reason to suppose that the arc would always become a complete circle. From what is to be seen in numerous cross-sections, it appears that the centers and degrees of curvature were subject to change at frequent but irregular intervals. It must be regarded as in some degree accidental that the composite line formed by the numerous arcs should eventually form a closed area. In fact, in the majority of cases, the line did not so close upon itself. In

such cases the concretion is not a closed tube, but is a more or less corrugated sheet, the corrugations, however, having the usual orientation. Such a corrugated sheet may be observed in the upper part of Fig. 4.

The formation of the secondary chambers of the compound concretions is to be ascribed to the same tendency to change the center of curvature. Ordinarily, new molecules coming in contact with the wall of a concretion simply went to increase the thickness of that wall, but not always. At any time some innovating molecule was likely to align itself so as to form a starting-point for a new arched surface, which would compel additional molecules to arrange themselves in conformity to its general scheme, until succeeding arches cut it off from further growth.

Editorial

In the deaths of Dean Nathaniel Southgate Shaler, of Harvard, and of Professor Israel Cook Russell, of the University of Michigan, American geology has lost two of its best-known and most popular writers on geology, as well as two of its most active and attractive personalities. The closeness of succession of these calamities, and the singular similarity of the fatal illnesses, give keenness to our regret. It is our hope to publish, in an early number of the *Journal*, full sketches of the services of these two men to our science. Awaiting the publication of these sketches, we wish to voice now the universal sorrow, not only of geologists and educators, but of the multitudes of intelligent people who have read with profit and delight the sketches of earth-lore that have come so freely from their fluent pens.

T. C. C.

Because of business engagements which will take him out of the state for some time to come, Dr. Frank G. Wilder has resigned his position as State Geologist of Iowa, and has been succeeded by his honored predecessor, Professor Samuel Calvin. Changes in the administrations of state surveys are to be deprecated generally, except when inefficient men retire; but in this case the parties most immediately concerned have worked together so intimately and in such perfect accord that the transition will be accomplished without even momentary interruption in the work of the survey, just as it did when Dr. Wilder succeeded Professor Calvin. Since a change in the administration was necessary because of Dr. Wilder's absence, both Iowa and the science of geology are to be congratulated that Professor Calvin is willing to resume the duties of an office which he filled so long and so well, and from which he voluntarily retired some years ago.

R. D. S.

Reviews and Book Notices

A Register of National Bibliography, with a Selection of the Chief Bibliographical Books and Articles Printed in Other Countries. By William Prideaux Courtney. 2 vols., 8vo. Pp. viii + 639. London: Archibald Constable & Co., 1905.

This book is not on geology, but it contains so much of value to geologists, mineralogists, and paleontologists that it seems well worth while to call attention to it. It is a bibliography of bibliographies, and though one might infer from the title that it was confined to British bibliographies, this is far from being the case. The author lives in London, and for some twenty years he worked more or less at this task, while during the last four years he devoted his time entirely to it. He has besides had the aid of many persons interested in special lines of bibliographic research, to say nothing of purely clerical work provided by himself.

The general titles are arranged in alphabetic order, and besides these there is at the end a full index covering seventy pages of closely printed names and subjects. Under the head of geology, besides the general bibliographies, there are given bibliographies of over one hundred countries, states, and special topics.

J. C. Branner.

The Dynamics of Faulting. By Ernest M. Anderson. (Transactions of the Edinburgh Geological Society, Vol. VIII, Part III [1905], pp. 387–403.)

By treating the subject in a mathematical and theoretical method the following conclusions are drawn:

Faults may be grouped roughly into three classes, known as reversed faults, normal faults, and wrench-planes.

a) Reversed faults and thrust-planes originate when the greatest pressure in the rock mass is horizontal, and the least pressure vertical. They "strike" in a direction perpendicular to that of the greatest pressure, and dip in either direction at angles of less than 45°.

b) Normal faults originate when the greatest pressure is vertical, and the least pressure in some horizontal direction. They "strike" in a direction perpendicular to that of least pressure, and dip in either direction at angles of more than 45°.

c) The third type of faults, to which the name of wrench-planes has been applied, originates when the greatest pressure is in one horizontal direction, and the least pressure in another horizontal direction, necessarily at right angles to the first. They "strike" in two possible directions, forming acute angles which are bisected by the direction of greatest pressure; their hade is theoretically vertical. E. W. S.

The Copper Deposits of Missouri. By H. FOSTER BAIN AND E. O. ULRICH. (United States Geological Survey, Bulletin No. 267, 1905.) Pp. 52, 1 plate, 2 figures.

Copper is widely distributed in Missouri in the form of sulphides and carbonates, but the deposits are not large, and only four mines have found it in workable amounts. The total value of copper so far produced has been variously estimated at from $20,000 to $50,000. The ores are believed to have been widely disseminated in crystalline and sedimentary rocks, and to have been concentrated by underground waters. The copper seems related to original shallow water conditions. It also shows a preference for certain horizons. This is believed to be due to unequal distribution at the time the rocks were formed. E. W. S.

The Geology of the New England Plateau, with Special Reference to the Granites of Northern New England (New South Wales). Part II, "General Geology;" Part III, "The Genesis of Ore Deposits." By E. C. ANDREWS, B.A. (Extract from Records of the Geological Survey of New South Wales, Vol. VIII [1905].) Pp. 45, 11 figures, 1 plate.

These papers treat of the geology of New South Wales; the occurrence of gold, wolfram, tin, monzite, bismuth, and other ores; and the close relation between their occurrence and certain acid intrusives. E. W. S.

The Geology of the Diamond and Carbonado Washings of Bahia, Brazil. By ORVILLE A. DERBY. Translated by J.C. BRANNER.

The diamonds occur in various formations, but principally associated with a heavy conglomerate, 6–10^{m} thick. About 250^{m} of sandstone lie above this conglomerate, and an equal thickness underlies it. Where diamonds occur in other formations in the region, they are thought to have been transported there from the conglomerate. The structure is Appalachian in type, and there has been much faulting and folding and erosion. The age of the conglomerate is unknown, but undisturbed Cretaceous sandstone is found near the folded conglomerate. E. W. S.

The University Training of Engineers in Economic Geology. By J. C. BRANNER. (Reprint from *Economic Geology*, Vol. I, December–January, 1906, pp. 289–94.)

This paper discusses the training necessary for success in economic geology. The author points out the desirability of considerable preliminary study of other subjects, and the necessity of training in pure geology.

E. W. S.

Red Beds of Southwestern Colorado and Their Correlation. By WHITMAN CROSS AND ERNEST HOWE. (Bulletin of the Geological Society of America, Vol. XVI [December, 1905]. Pp. 447–98, Plates 82–85.)

A marked unconformity occurs in the Red Beds of this area, and several photographs of it appear in this article. The formation above the break is classified as Triassic on the basis of vertebrate fossils; that below is assigned to the Permian. E. W. S.

Taconic Physiography. By T. NELSON DALE. (U. S. Geological Survey, Bulletin No. 272, 1905.) Pp. 52, 14 plates, 3 figures.

There have been three periods of folding in the region—first, at the close of the Lower Cambrian; second, at the close of the Ordovician; and third, in Devonian or Carboniferous time. The topography is the result of the erosion of rocks which vary in composition and structure. The lakes and some other features are due to glaciation. E. W. S.

Underground Waters of Eastern United States. By MYRON L. FULLER. (Water Supply and Irrigation, Paper No. 114, U. S. Geological Survey, 1905.) Pp. 272, 18 plates, 40 figures.

This report is prepared primarily for drillers and treats of the occurrence of underground waters. It is a compilation of material from numerous local geologists. E. W. S.

Fire Tests of Some New York Building Stones. By W. E. MCCOURT. (New York State Museum, Bulletin No. 100.) Albany, 1906. Pp. 38, 26 plates, and index.

The purpose of testing the building stones was to acquire definite information regarding their fire-resisting qualities. The rupturing caused by heat, with slow, or with sudden cooling, varies considerably with different rocks. The order of the refractoriness of rocks tested is: (1) sandstone, (2) fine-grained granite, (3) limestone, (4) coarse-grained granite, (5) gneiss, and (6) marble. E. W. S.

Contributions to the Hydrology of Eastern United States, 1903. By MYRON L. FULLER. (Water Supply and Irrigation, Paper No. 102, U. S. Geological Survey, 1904.) Pp. 512.

This paper covers the hydrologic work done in the eastern United States in 1903. The statistics are arranged by states. The information was collected by many local geologists, and compiled and prepared by Mr. Fuller.

E. W. S.

The Sources of Water Supply in Wisconsin. By WILLIAM GRAY KIRCHOFFER, C.E. (Bulletin of the University of Wisconsin, No. 106.) Pp. 113, 3 plates, 3 diagrams, and 21 tables and index.

The bulletin is a compilation of data regarding the water used by cities and villages in Wisconsin, together with many interesting observations thereon. The sources are classified, and the factor entering into occurrence and use are discussed. E. W. S.

The Geology of the New Hebrides. By D. MAWSON, B.E., B.Sc., Lecturer in Mineralogy and Petrology at the University of Adelaide. Pp. 85, 14 plates, 7 figures. (Proceedings of the Linnean Society of New South Wales, Part III, October, 1905.)

Little has been known of the New Hebrides because of the hostility of the natives and the prevalence of malaria. The group of islands was developed as a fold in the Miocene, and intrusion and extrusion of andesitic lava accompanied the folding. About Middle Pliocene there was renewed volcanic activity along a new line, and this has continued to the present. This later flow is basic, and was probably immediately preceded by faulting. Recent uplift has carried coral reefs up to 2,000 feet. These are underlain by tuffaceous beds. The uplift is one-sided, being less on the east side, where the centers of eruption are.

Biological evidence points to connection of the islands with other land masses early in their history.

The author points out that the South Pacific Islands are lined along great fold-chains, concentric with Australia, and puts the New Hebrides, Sumatra, New Caledonia, and New Zealand in one of these chains. The discontinuity of the land is referred to cross-faulting, incident to folding. He believes that the land area was much larger and more continuous in the early Tertiary, and that the breaking up began then. From evidence of coral reefs, it appears that in these and many other islands of the South Pacific the first movement was true folding, and this was followed by horizontal uplift. The petrology, paleontology, and other features of the islands are treated in some detail. E. W. S.

A Dictionary of Altitudes in the United States, Fourth Edition. Compiled by HENRY GANNETT. (Bulletin No. 274, U. S. Geological Survey, 1906.)

The material of previous editions has been revised, and many new data have been added. E. W. S.

Twenty-sixth Annual Report of the Director of the United States Geological Survey, 1904–5. Pp. 322, 25 plates (maps), 1 figure.

A classified report of the work of the United States Geological Survey for the year. E. W. S.

The Economics of Mining. By T. A. RICKARD. Pp. 421; cloth.

This volume is composed of nearly a hundred editorials and short articles which have appeared since January, 1903, in the *Engineering and Mining Journal*. E. W. S.

Mesozoic Section on Cook Inlet and Alaska Peninsula. By T. W. STANTON AND G. C. MARTIN. (Bulletin of the Geological Society of America, Vol. XVI [June, 1905].) Pp. 391–410, Plates 67–70.

Upper Trias, Lower, Middle and Upper Jurassic, Upper Cretaceous, and probably Dower Cretaceous are found to be represented, and, except the Middle and Upper Jurassic, are usually, at least, separated by unconformities. Nearly 10,000 feet of strata are referred to the Jurassic. The fauna at this period is also well developed, and is Russian or boreal in type. E. W. S.